THE

QUADRUPLEX.

BY

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WITH CHAPTERS ON

The Dynamo-Electric Machine in Relation to the Quadruplex. The Practical Working of the Quadruplex. Telegraph Repeaters, and the Wheatstone Automatic Telegraph.

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PREFACE.

WHEN the authors of the following description of the Edison quadruplex system of telegraphy undertook to write a clear and complete explanation of that system, and of the instruments connected therewith, they felt convinced that in doing so they would meet with encouragement from many of their fellow operators, especially those who had not had a favorable opportunity to study the theory or to investigate the practical working of the system.

They were aware that among the employes of the various telegraph companies there were many who were and are deterred from gaining a closer acquaintance with the more complicated systems of telegraphy, for the reason that the text books are, as a rule, beyond their comprehension, and, therefore, the information they are in search of can only be obtained by persistently questioning those who are better informed than themselves, a method requiring much patience, and not always an agreeable one.

To meet the wants of this class was their principal object, and they have been pleased to find that, judging by the reception which greeted the appearance of the articles in the pages of *The Operator*, their efforts have been successful.

In the following description of the quadruplex, as well as in the other articles contained in this book, no attempt has been made to display erudition. On the contrary, it has been the aim of the writers, if they erred at all, to err on the side of simplicity.

It is a book written by operators for operators, and numerous

assurances have been received, that, as such, it has been useful. But while such is the case, they also hope, and have reason to believe, that it will be found an easy source of information to those outside of the telegraphic fraternity, who may desire to form an acquaintance with these various systems and instruments.

The authors take this opportunity to return acknowledgments to Mr. C. O. Mailloux for valuable hints as to the construction of the diagrams. The majority of the diagrams were prepared for the engraver by the same gentleman.

In conclusion, the writers hope that their book will prove to be free from serious blunders, and that all who find profit in reading what is herein written may be induced thereby to seek to increase their knowledge of electrical matters by a study of more elaborate works on such subjects.

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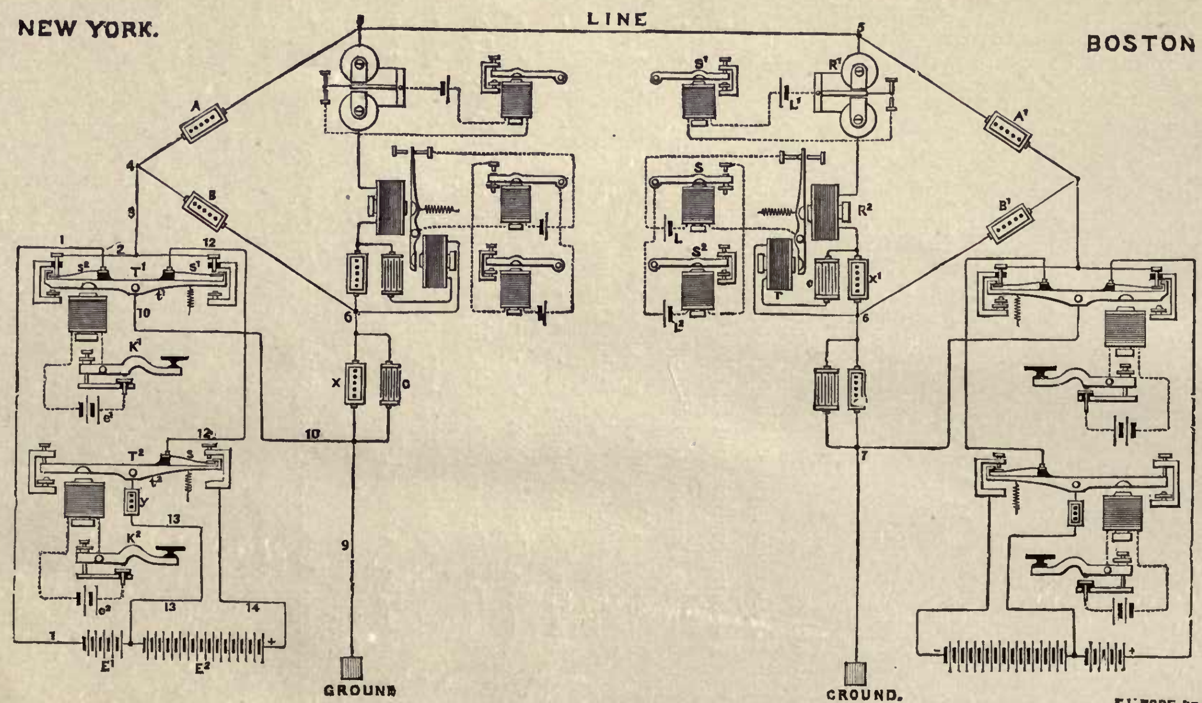


Fig. 1.—ORIGINAL EDISON QUADRUPLEX.

THE QUADRUPLEX.

CHAPTER I.

DEVELOPMENT OF THE QUADRUPLEX.

In 1874, Mr. Thomas A. Edison succeeded in getting his quadruplex into such shape that it was considered fit to be used on wires for the transaction of commercial business.

The first quadruplex circuit on which business was actually transmitted, was between New York and Boston. At this time the quadruplex was worked on what is known as the bridge system, as seen in Fig. 1, that is, the receiving instruments were placed in the arm usually allotted to the galvanometer in the Wheatstone bridge, and of course were operated by the excess of current passing through that arm precisely as a galvanometer would be.

At this time the instruments were not wound differentially.

The No. 2 relay was then, as now, a neutral relay, with a soft iron armature, but with an ordinary long core.

At that early stage of the history of the quadruplex system, it cannot be said that it was a complete practical success.

The principal difficulty appears to have been caused by the unsteadiness of No. 2 relay, and this was attributed to the falling back of the armature of the No. 2 relay at the moment when there was no battery at the distant end, namely, while the change of polarity was taking place; but, in the light of subsequent experience, it may perhaps be questioned whether this was really the case.

To assist in obviating this trouble, the armature lever of that relay was made very long, and at its other end it was furnished with an armature placed opposite another electro-magnet, which electromagnet was in a shunt circuit in which was also placed a condenser.

This condenser, at the moment of change of polarity at distant end, discharged into the shunt circuit, and, by thus magnetizing the extra electro-magnet, held the lever firmly against the contact point for the desired time.

In 1875 a change was made in the foregoing arrangement, the same principles being retained, but the differential method was adopted and both Nos. 1 and 2 relays were polarized.

The armature of the No. 2 relay of course responded to all changes of polarity, but its contact points were so arranged that when the full strength of current was to the line, the retractile springs were overcome and the local circuit broken as seen at R^2, Fig. 2.

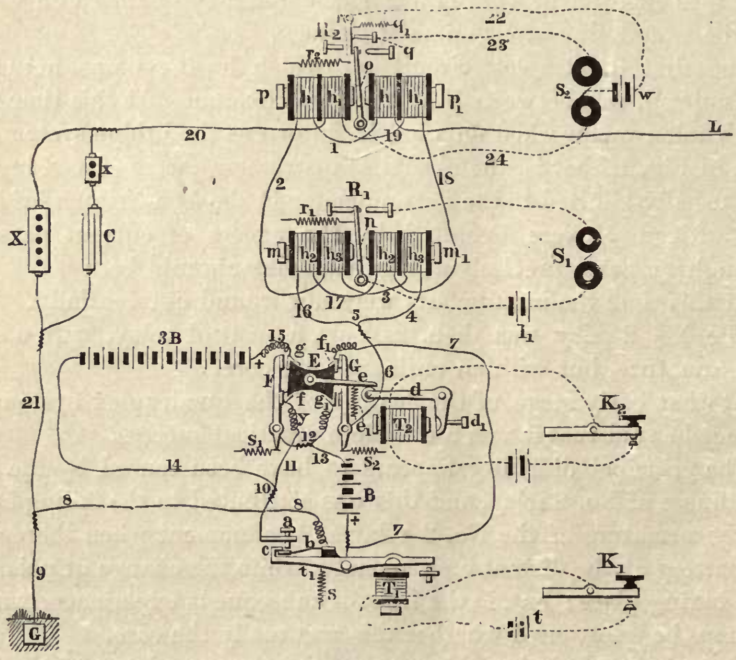


Fig. 2.

The next alteration, shown in Fig. 3, consisted of a novel arrangement of the circuit, which did not require the polarity to be reversed during the transmission of a signal. The diagram shows the con-

nections necessary for working this device on the diplex system, that is, for sending two messages in the same direction simultaneously. By the adoption of any of the duplex systems, this method can be converted into the quadruplex system. Mr. Gerritt Smith was the inventor of this ingenious arrangement.

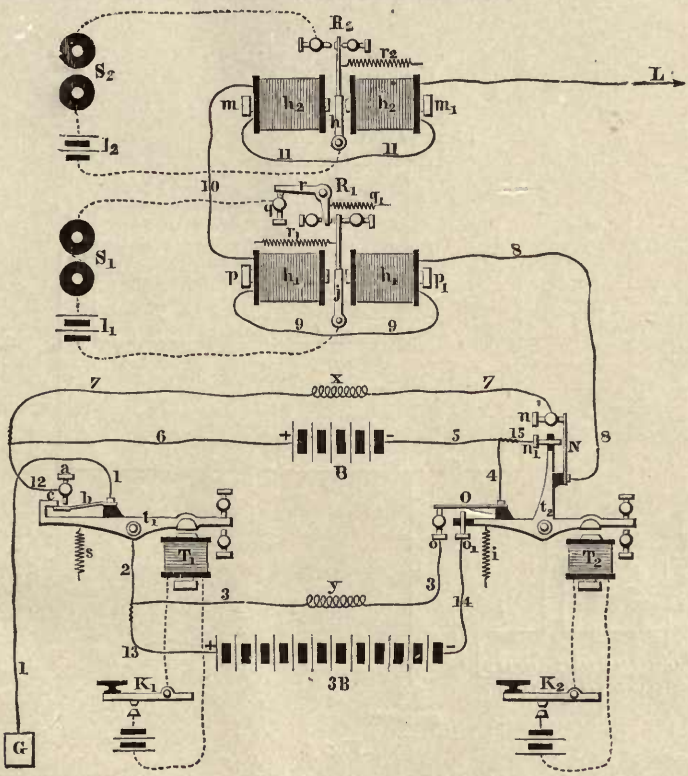


Fig 3.

Following this came a supposed improvement of the original arrangements of the quadruplex (Fig. 4), which, as may be seen, is a combination of the bridge and differential methods. The No. 1 relay was placed in the bridge, and the No. 2 relay (now transformed into a compound polarized relay, also an invention of Mr. Gerritt Smith,) was placed in the line and the rheostat wires, as at present.

As in the former case the No. 2 relay, R^2 in the figure, responded to either polarity, but only broke the local circuit when full battery was to the line at distant end. Subsequently both relays were again placed differentially, a polarized relay, for increase and decrease of strength, still being retained. (Fig. 5.)

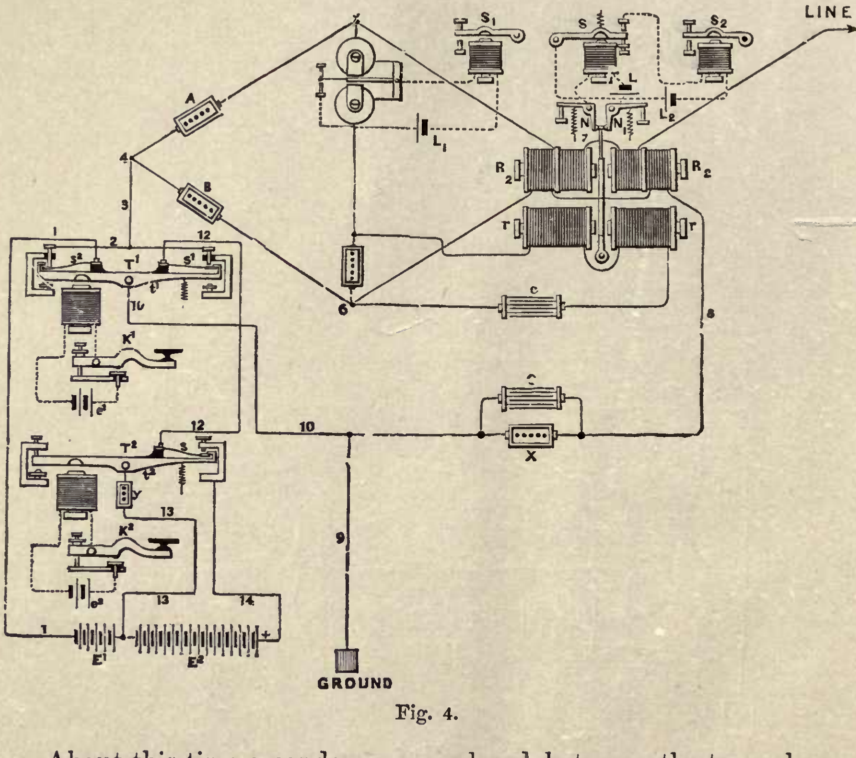


Fig. 4.

About this time a condenser was placed between the two relays, one series of its plates being connected to the rheostat wire, the other series to the line wire, which was found to be of service. This arrangement was devised by Mr. F. W. Jones, at that time in Chicago.

About this time also a combination relay, shown in Fig. 6, capable of performing the service of the present No. 1 and No. 2 relays was

introduced. It may be seen by following out the local connections that the armature will give the correct signal for increase and decrease of strength, regardless of the side on which it may be giving a polarity signal. This device worked successfully, but it was found

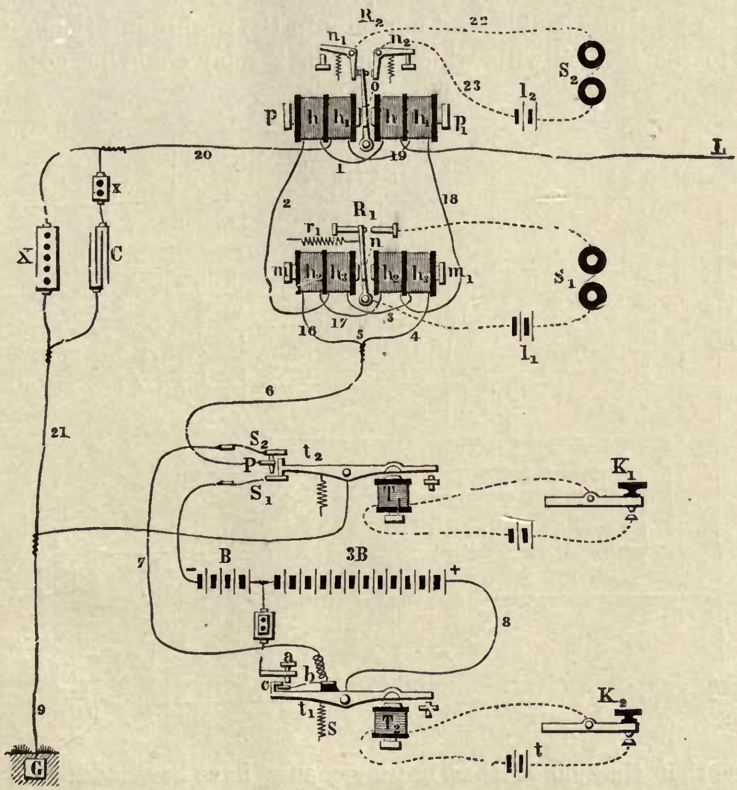


Fig. 5.

more desirable to have two separate relays so that each receiving operator could have control of the adjustment of his own instrument.

Fig. 7 shows the stage at which the system had arrived in 1878, four years after its first appearance.

At that time the compound polarized relay was still used as the

No. 2 relay. The local contact points, as heretofore, were so arranged as to close the local circuit only when full battery at distant end was to the line.

Then followed the introduction of the short core No. 2 relay, upon the advent of which a marked improvement in the working of the system was discernible, and not only in the working of the system, but in the facility with which the No. 2 relay could be adjusted.

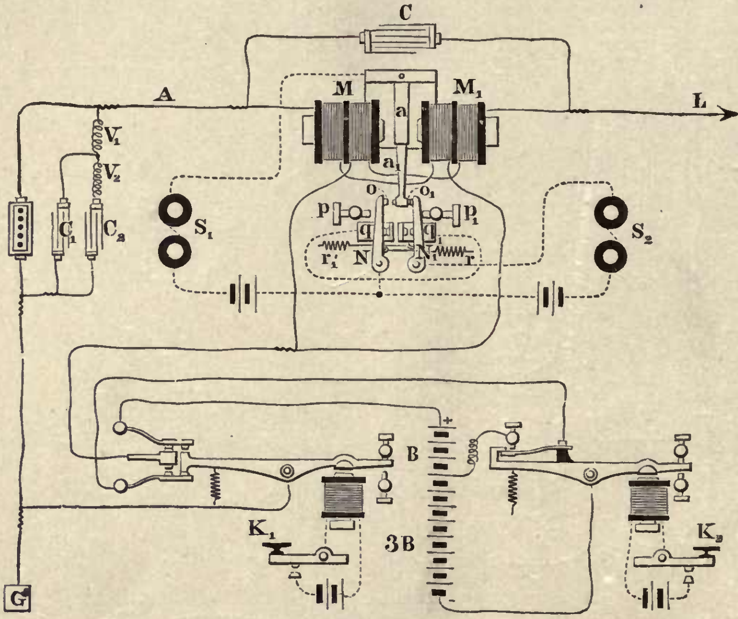


Fig. 6.

Since that time no further improvements have been added to the system. Indeed, it is difficult to imagine in what respects it could now be improved. In fair weather and under good conditions as regards management, etc., the system approaches very near perfection.

The continuity preserving transmitter has retained its original shape throughout, but the pole changer has seen about as many changes in the form of its construction as there have been methods

employed in the endeavor to bring the quadruplex system to its present shape.

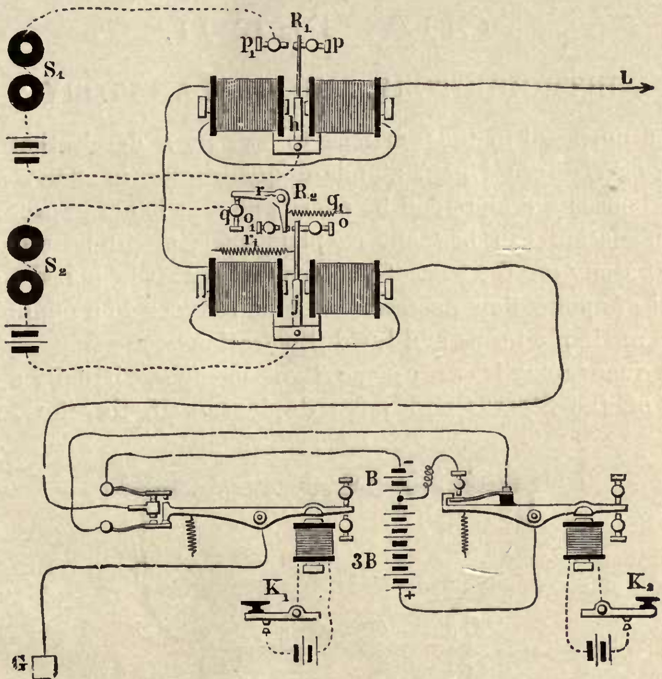


Fig. 7.

We are mainly indebted to Prescott's description of the quadruplex for the foregoing information.

CHAPTER II.

INTRODUCTORY AND EXPLANATORY.

It is purposed in these articles to present a description of the Edison or Western Union standard quadruplex in such a manner as will be easily understood by every one. It is not expected that the explanation can be made so plain that it will be understood without study on the part of the reader; but it is hoped that the amount of application necessary will be reduced to a minimum by the use of simple terms and lucid illustrations.

This quadruplex is, with some slight changes, virtually a combination of the Stearns and polar duplexes. If, therefore, we acquire a distinct knowledge of the theories of these duplexes, it will be comparatively an easy task to comprehend the manner of their combination in the quadruplex.

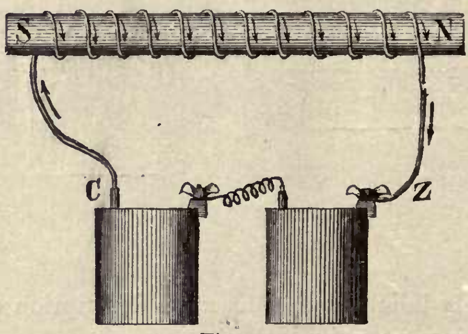


Fig. 8.

The instruments used in the working of these duplexes are similar to those required in the quadruplex, namely, the single-current transmitter and neutral relay of the Stearns system, and the pole changer and polarized relay of the polar.

The function of the single-current transmitter is to increase and

decrease the strength of current on the line: that of the pole changer is to change the direction of the current.

The office of the neutral relay is to respond to the increase or decrease of current on the line, while that of the polarized relay is to respond to the changes of polarity of the current. Both relays are wound differentially, as will be explained.

Here are two distinct principles which, when properly combined, give us the quadruplex.

We will proceed to inspect the manner of working the Stearns duplex, but, before doing so, it will be necessary to examine some of the laws of electricity and magnetism on which its operation is based.

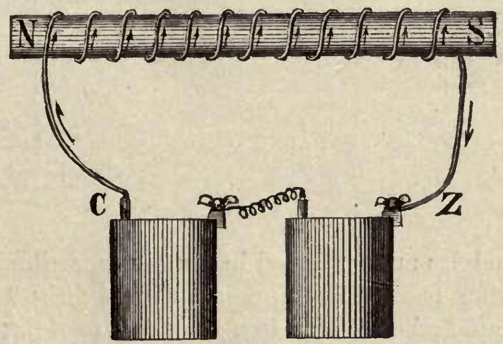


Fig. 9.

If electricity be passed through a coil of wire encircling a bar of soft iron, the bar will become a magnet, the polarity of which will be determined by the direction in which the current passes around the bar. The iron will, however, lose its magnetism the moment the current ceases. If the wire be wound around the bar, as shown in Fig. 8, and if the current be passing in the direction indicated by the arrow *S*, the poles will be as indicated in the figure.

Winding the wire in the opposite direction around the bar, the current retaining the same direction, reverses the polarity of the magnet, as shown in Fig. 9.

It follows that if two *equal* currents are caused to pass around the bar in opposite directions, tending to establish exactly opposite

effects, they will neutralize each other, and the bar will remain non-magnetic.

If we bend the bar to the form of a letter U, both poles of the magnet will exert whatever attractive force is developed, upon an unmagnetized cross piece, or armature, as may be seen in ordinary relay and sounder magnet.

If we connect one pole of a battery with the earth and from the other pole run to the earth two wires of equal resistance (Fig. 10), equal currents will traverse the wires.

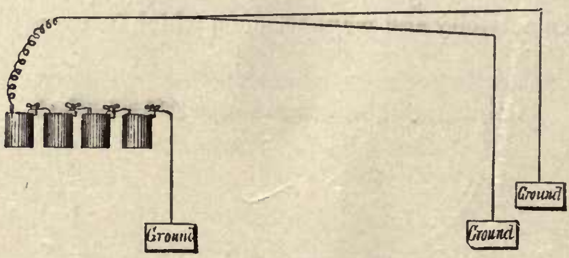


Fig. 10.

These principles are employed in the Stearns differential system in the following manner: Suppose a wire *A* (Fig. 11) is led from a battery around a bar of soft iron from left to right, over the bar, and another wire of equal resistance *B* around from right to left, two equal opposing actions will be set up in the bar, one exactly offsetting the other, and no magnetic effect will be produced. A relay thus wound is called a differential relay.

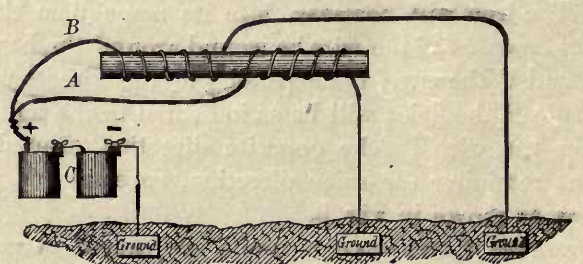


Fig. 11.

Now, suppose a battery is introduced at the distant end of *B* (Fig. 12), and note the result.

Battery *C* supplies each wire with an equal current, having a strength of, say, 2. Battery *D* adds to the strength of the current traversing wire *B* an additional strength of 2, making a strength of 4 upon wire *B*, a surplus of 2 above that on *A*, which is sufficient

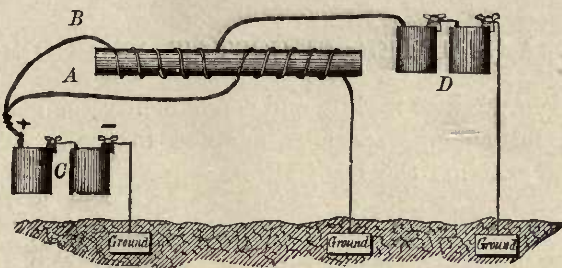


Fig. 12.

to neutralize the magnetism which the current in wire *A* would tend to set up, and to establish, by means of its excess of strength, a magnet, the polarity of which is determined, as in the previous cases, by the direction of the current *around the bar.*

Let us take an illustration frequently used. Suppose a wheel (Fig. 13) upon the opposite sides of which two streams of water

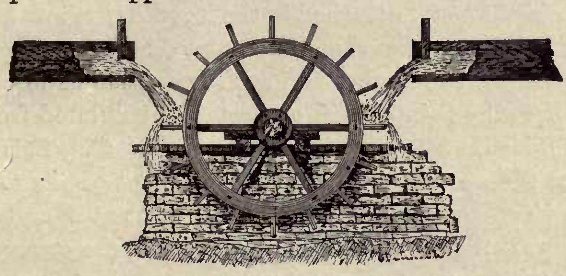


Fig. 13.

are falling with equal force. So long as these forces continue equal the wheel does not move, but upon increasing the pressure on one side, the force acting upon the other will be overcome, and the wheel will revolve. In a similar manner the excess of electrical force in one of the coils overcomes the opposing force in the other.

CHAPTER III.

THE TRANSMITTER, RHEOSTAT AND CONDENSER.

In order to produce rapidly and conveniently the magnetic effect described, instruments specially adapted to the work are used. Let us first examine the transmitter.

The Transmitter.

In the Stearns duplex, the office of the transmitter, or continuity preserving key, is to alternately place the battery and the earth in contact with the line, substituting one the instant the other is removed; thus preserving, with the exception of a slight interval noted further on, a continuous circuit at all times.

A (Fig. 14) is an electro-magnet controlling, by means of local battery *L B* and key *K*, the action of armature lever *B*. *C* is a thin tongue of elastic metal attached to the lever *B*, but insulated from it. The lever *B* is bent at one end, as shown, and the tongue extends just below the arm of the bend in such a position as to come in contact with it at the point *X*. The post *D* is insulated from the base upon which it stands, and supports the screw *G*. This screw is so adjusted as to intercept the upward movement of the tongue when the transmitter is closed, establishing contact at *E* and breaking it at *X*. Now, if the battery be connected to *D*, the ground to *B*, and the line to the tongue *C*, the instant we close the transmitter, screw *G* places the battery in contact with the line at *E*, while it pushes the tongue downward at *X*, breaking contact at that point. The screw *S* regulates the play of the armature lever. The relay used in the Stearns duplex is differentially wound, but is otherwise constructed like those in ordinary use.

The Rheostat.

In the systems of duplexes and quadruplex which we are studying, we have two wires wound around the cores of electro-magnets in opposite directions, so that the currents from the home battery have no effect upon the cores, as one current neutralizes the other; in other words, one wire balances the other.

By placing another battery at the distant end of one of these wires, however, we have seen that we can diminish or increase the

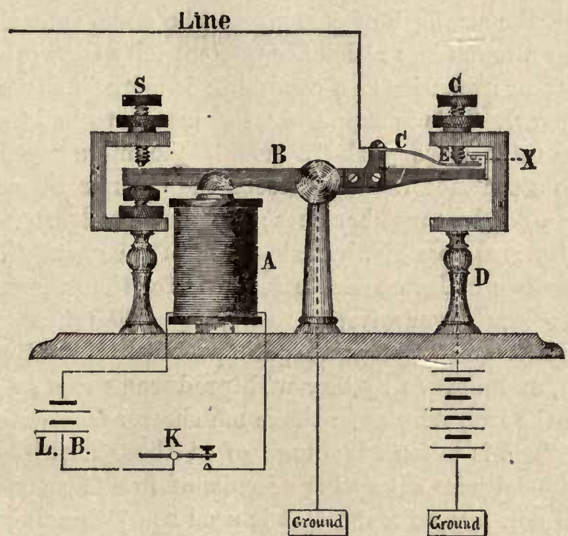


Fig. 14.—The Transmitter.

strength of the current passing through that wire so that the equilibrium which the home battery tends to maintain in the cores is overcome, and we can thus operate the home electro-magnets from the distant end, at will. Now, as the object of the multiplex systems is to double or quadruple the capacity of the existing wires between any two places, it is evident that one of the wires which we use to preserve the equilibrium in the electro-magnets must be comparatively of no expense, or nothing will be gained. For instance, if we desired to set up a duplex between any two points,

and were to use two of the wires already running to those points, one wire to balance the other, it is manifest that, although we should literally make one wire do the work of two, we should actually still be using two wires to accomplish the feat.

It is a law of electricity that with a given electro-motive force the strength of current will depend on the resistance of the conductors through which the electricity is required to pass.

It is not necessary that the two wires should be of the same length, size, or material. Provided the resistance of the conductors is the same, the strength of current will be equal in each. Certain metals offer a much less resistance to electricity than others. Thus the capacity of iron wire as a conductor is more than twice that of German silver. This is supposing the metals to be of equal thickness. The thicker we make a metal, the more we increase its capacity as a conductor. Conversely, the thinner we make a metal the poorer a conductor it becomes; in other words, its resistance is greater. So it is possible, by using iron of a certain thickness for one of the wires under consideration, and for the other a very much thinner German silver wire, to make, say, 500 miles of iron wire equal in point of resistance to perhaps but half a mile of German silver wire, and a given battery will produce as great a strength of current in the iron wire as in the much shorter German silver wire. This fact, then, is taken advantage of in these multiplex systems, and an artificial wire consisting of coils of fine German silver contained in a box termed a rheostat is used as a balancing wire.

Fig. 15 shows the manner in which the coils are connected to the brass discs on the cover of the box and to each other. A brass plug inserted between any two of the discs virtually cuts out one of the coils, as it provides a route of practically no resistance for the current. The coils are wound double upon themselves, as shown in the figure, which prevents any inductive effects, the law of electricity bearing on this point being "that a circuit doubled back upon itself so that the current flows back along a path close to itself exerts no force upon external points."

Thus we have a simple means of obtaining a wire which we can

adjust to correspond with a line wire of almost any resistance. If, for example, we have a wire, as in the figure, 3,000 ohms resistance, we simply unplug as many coils in the rheostat as may be necessary to bring the artificial wire up to the same resistance, and if by reason of wet weather the resistance of the line wire decreases, we reduce the resistance of the rheostat by inserting more plugs between the discs; for, if we do not preserve the balance be-

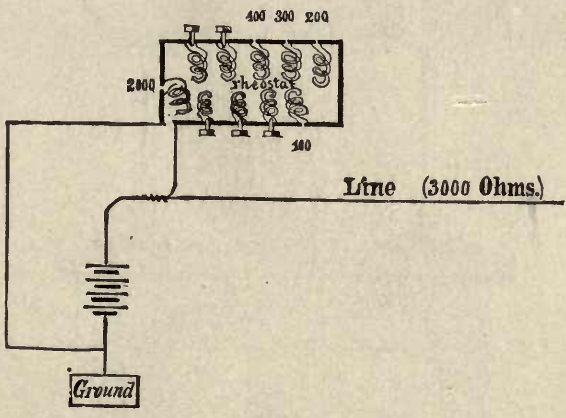


Fig. 15.

tween the two wires, the home battery will operate the home relays and thus interfere with the signals from the distant end. The figures on the brass discs represent the amount of the resistance in ohms of the coils attached to them.

The Condenser.

As without the use of condensers or some other instrument capable of performing a similar service, it would be impossible, for reasons which will be explained hereafter, to successfully work the multiplex systems on lines of any great length, it will be proper to devote some space to a description of their action and manner of construction:

It is a well known law of both electricity and magnetism that like poles repel and unlike poles attract each other.

If by any means we electrify any insulated conductor with electricity of one polarity, that electricity will tend to attract toward itself in surrounding objects sufficient electricity of opposite polarity to establish equilibrium, or what is termed a non-electric state.

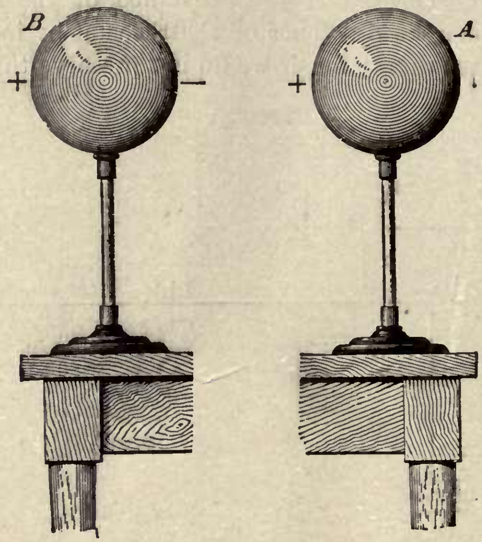


Fig. 16.

Electricity thus attracted in surrounding conducting objects is called induced electricity, and this property of inducing electricity in other objects is termed induction. All substances are not equally susceptible to inductive influence. Good conductors of electricity generally are, while insulators are not. In Fig. 16, *A* and *B* are supposed to be insulated metal spheres remote from other conducting bodies. If *A* be charged with positive electricity from an electrical machine, it will at once receive all the electricity which it will apparently hold. If *B* be now brought close to *A*, it will be found that *A* will receive more electricity, because the positive electricity on *A* has attracted a corresponding quantity of negative electricity on the side of *B* nearest *A*, and has repelled an equal amount of positive electricity to the opposite side of *B*, and in the

effort of the two polarities to unite they have become gathered or condensed upon the sides of the spheres nearest each other. If we now connect *B* with the earth, thus allowing the positive electricity on *B* to escape, it will be found that *A* will receive a still further charge of positive electricity, and *B* will take up a corresponding amount of negative electricity. So long as *A* is kept electrically charged, the electricity which has been induced in *B* will be held

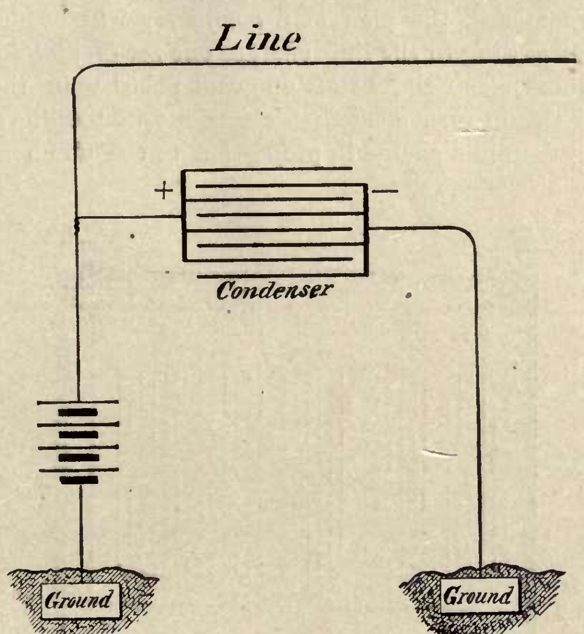


Fig. 17.

in *B*, but the instant we provide a conductor to the earth for *A*, the induced electricity in *B* will simultaneously flow to the earth.

We cannot interpose any known substance between the spheres which will prevent the above described inductive action from taking place. The least inductive effect is produced when the plates are separated merely by air; the greatest when they are separated or insulated by mica. The closer the plates can be brought without touching, the greater the inductive effects will be.

Condensers are constructed in accordance with the foregoing laws. They are, therefore, generally composed of sheets of tin-foil connected alternately to a battery wire and to the earth, as seen in Fig. 17. Each sheet is separated from the other by some insulating substance, preferably mica, on account of its thinness and high inductive capacity, although paraffine paper is frequently used. Supposing the lines in Fig. 17 to represent the foil, and the spaces the insulating material, the plan of a condenser will be understood. The current passing to the line charges one set of plates as shown, which induces electricity of an opposite polarity in the ground plates, and this in turn condenses electricity in the line plates, accumulating therein a charge in proportion to the number of plates in action.

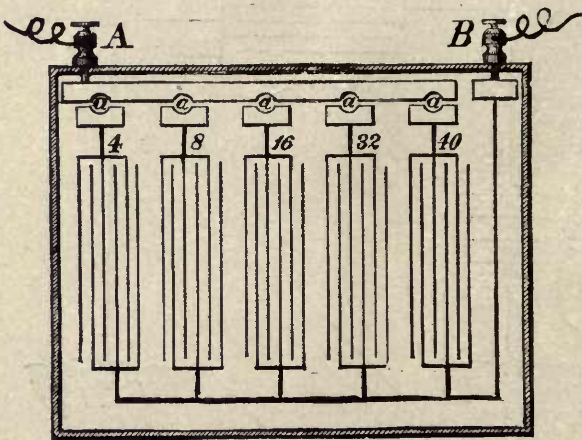


Fig. 18.

In Fig. 18 the general plan of the condenser is shown. All the lower plates are connected with the thumb-screw *B*, which can be readily connected with the earth, and the upper plates to *A*, to which the line can be attached. By inserting plugs at *a a a a a*, more plates may be connected, and thus the amount of charge increased as desired.

CHAPTER IV.

THE STEARNS DUPLEX.

Fig. 19 is a diagram showing the theoretical arrangements necessary to the working of this duplex system.

In it T and T' are transmitters worked by means of a local battery and key. R and R' are relays differentially wound. E and E' are resistance coils, or rheostats, which furnish a method of making an artificial resistance equal to that of the line. H and H' are condensers, the manner of use of which will be explained later on.

Having made the rheostat resistance equal to the line resistance, we have at each end the conditions described in Fig. 12; the line wire representing wire B of that figure and the rheostat wire A, the core of each relay being equivalent to our soft iron bar.

Now let us see what takes place. Suppose T to be closed, and T' open. (In the diagram both transmitters are represented as closed.) In this position of the transmitters it is seen that battery F is in contact with the line, while battery F' will be cut off at G'.

Thus equal currents from battery F will pass in opposite directions around the cores of relay R, one portion going to the ground through coil A of relay R, and the rheostat; the other, via the line and through coil B' of relay R' to the ground at Q'. Thus battery F produces no effect on relay R, but in traversing coil B' of R' it magnetizes the core of the latter, and its armature is attracted, recording a signal. Let us say that the current from battery F in passing through coil B' of R' produces a magnetic strength of 2 in the core of the latter. Let us also grant, for the sake of illustration, that it is passing through coils A and B of relay R with a strength of 2 each—but owing to the fact that this strength is exerted in opposite directions no effect is perceptible—and let this

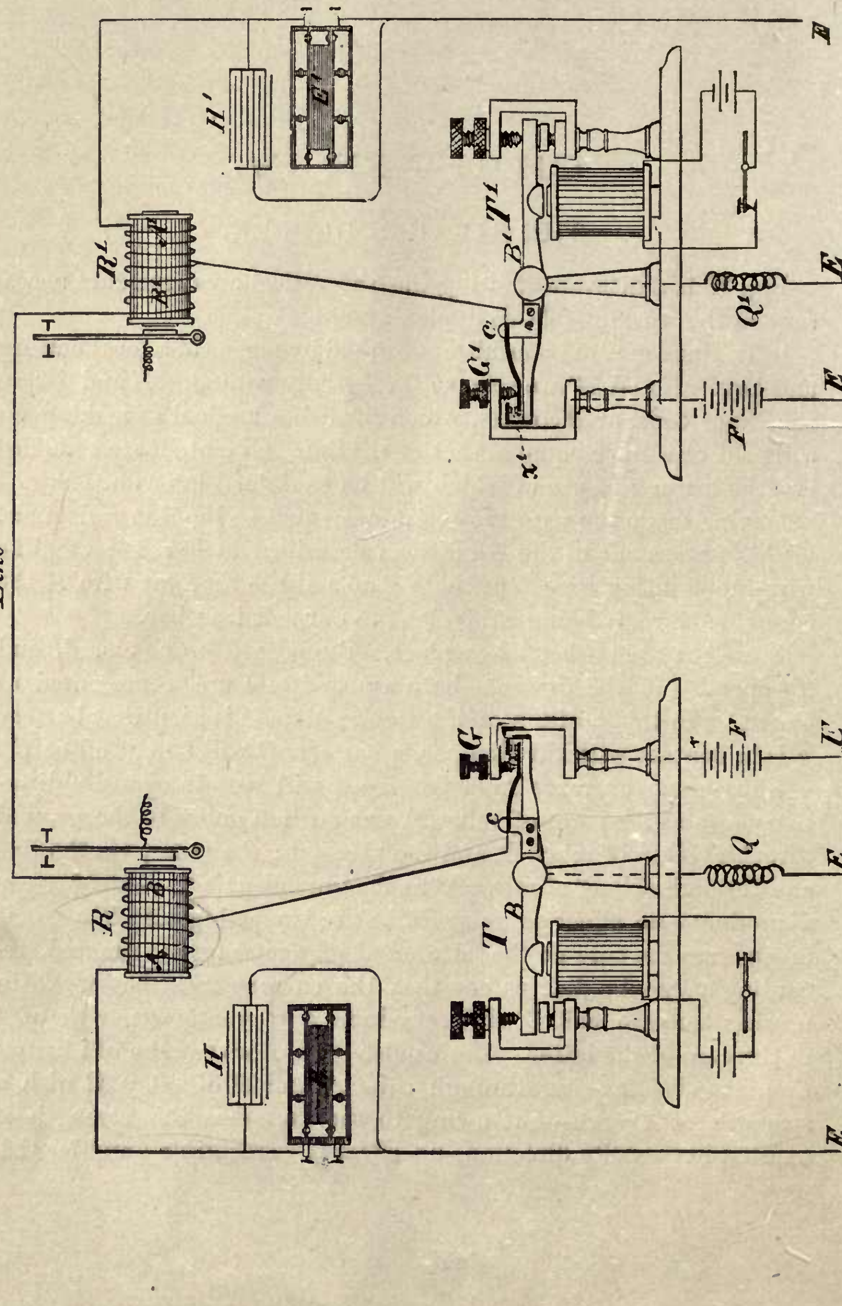


Fig. 19.—THE STEARNS DUPLEX.

also be true of the effect of battery F' on the cores of relay R', when F' is placed in the circuit, viz., that it has a strength of 2.

Should transmitter T' be now closed, as in the figure, breaking circuit at x', and placing battery F' in the circuit, wire a' of relay R' will now carry a current of a strength of 2, but an additional strength of 2 has been given to the current traversing wire B'. Wire B' of relay R' therefore still carries a greater current than wire A' of the same relay, viz., as 4 to 2, consequently that relay remains closed, while the current in wire B of relay R is also increased by the current of 2 from battery F', and is now of greater strength than that upon wire A of that relay, hence magnetism is produced in its core, and the armature is attracted, both relays being now closed. If transmitter T be now opened, it will be seen that the current from battery F is removed from the line, and the currents in wires A' and B' of relay R' become equal, consequently the core of that relay loses its magnetism, and the armature is pulled back by the retractile spring, opening the local circuit; but, as there is still a current in coil B of relay R, and none in coil A, that relay remains closed. Thus it is seen that under all circumstances battery F produces an active effect only on relay R', and that battery F' only operates relay R, and hence two messages may simultaneously be sent in opposite directions.

A line wire acts to a certain extent like a condenser. When it is connected with a battery it becomes charged, and whenever the proper conditions exist along its route it will induce electricity in adjoining conducting objects, and thus is enabled to take up a greater charge. In this duplex system, when we open the transmitter, and thus suddenly cut off the battery, and substitute a path to the earth, a portion of the charge will come back, and pass to the earth by this route rather than overcome the greater resistance to the distant end.

This discharge varies in quantity with the strength of the charging battery and the length and size of the wire. Thus there are many short duplex and quadruplex circuits on which this line discharge, or static discharge, as it is often called, is so small or dis-

charges itself so quickly that no effect is produced on the instrument. But on long circuits it becomes so great that in passing through the line coil of the relay a momentary magnetization of the core is caused, which attracts the armature and makes a false signal. In order to counteract this effect, a condenser, which can be adjusted to equal the accumulative capacity of the line wire, is connected to the rheostat coil of the relay (as seen in the diagram) so that its discharge may traverse that coil in an opposite direction around the core, and at the same instant that the line discharge traverses the line coil, thus neutralizing the effect of that discharge. Further allusion will be made to the action of the condenser when we consider the quadruplex.

The elements of batteries, that is, the zinc, copper and liquids, offer resistance to the passage of the current through them; this is called "internal resistance." In order to keep the resistance the same whether the circuit is completed through the battery, or through the armature lever of the transmitter, to the earth, resistance coils Q and Q′ (Fig. 19), having a resistance equal to the internal resistance of the home battery, are inserted between the levers of the transmitters and the earth.

CHAPTER V.

INSTRUMENTS OF THE POLAR DUPLEX.

The Pole Changer.

Figure 20 presents an end view of a pole changer, with its theoretic battery connections.

The square *B* represents one end of the armature lever, which protrudes through a hole in the center of the disc *K*. The squares on either side are screwed to the metallic disc *K*, but the tongues *T* and *T′*, each having two contact points, while supported by the

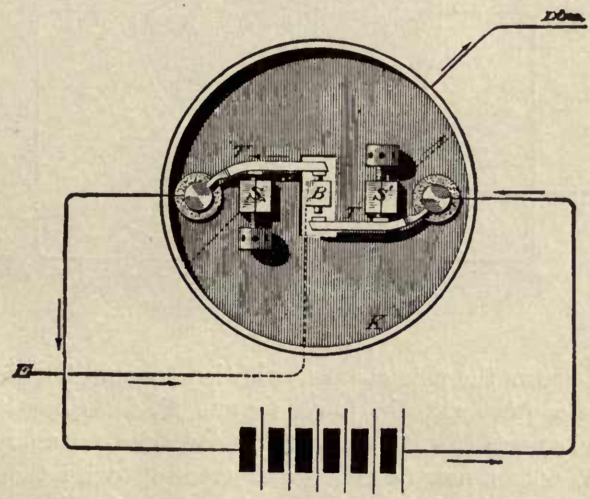


Fig. 20.

disc *K*, are insulated from it. Each tongue is connected to a pole of the battery. The bar *B*, or armature lever, is connected to earth. The line wire is connected to the disc *K*. In the figure, the key of local circuit controlling the pole changer is presumed to be

closed, hence the lever *B* has made contact with the upper tongue *T*, raising it from the square *S* on the left hand side, and has at the same time released the lower tongue which has risen by its own tension and made contact with the square on right hand side. The circuit is thus complete, from the earth at *E*, through lever, to the upper tongue *T*, to the negative pole of the battery, through battery to the lower tongue *T'*, thence to the line. Thus in this case the positive pole of battery is to the line, and the direction of the current is shown by the arrows.

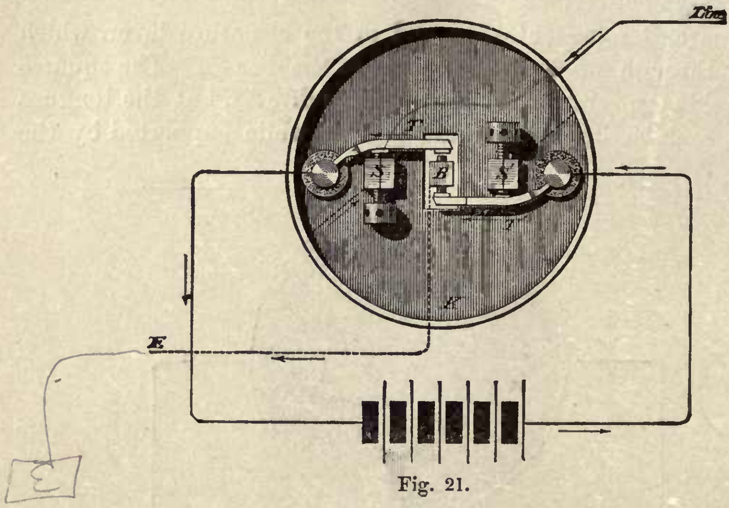


Fig. 21.

Fig. 21 shows the pole changer with key open. The lever *B* has now made contact with the lower tongue *T'*, detaching it from the right hand square *S*. It has at the same time released the upper tongue *T*, which now descends and connects with the left hand square *S*. The circuit is again complete, from the line to square *S*, to tongue *T*, to negative pole of battery, through battery to lower tongue *T'* and earth, and the direction of current is now changed as shown by arrows. Thus at each motion of the lever, up or down, the poles are changed and, consequently, the direction of the current.

In Figs. 8 and 9 we have seen that according to the direction of the current around the bar is determined the magnetic polarity of the bar. In those cases the direction of the current *around the bar* has been changed by winding the coils in opposite directions, so that the current has been made to go around the bars in different ways. We might have obtained the same results by changing the direction of the current *on the wire* and leaving the coil wound in one way. If we know the direction in which a current is traversing a bar, we can tell the position of the magnetic poles of the bar by the following rule: Suppose that we are looking at one

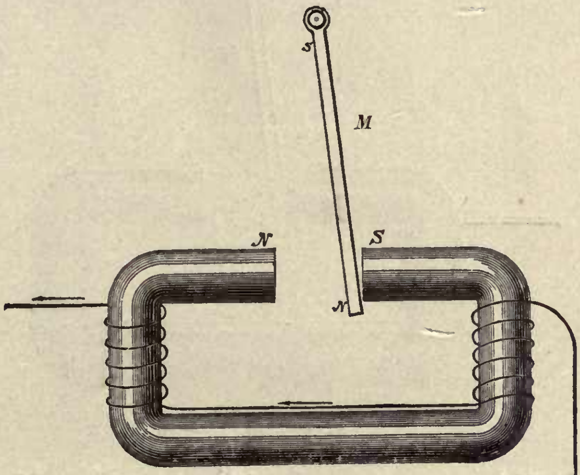


Fig. 22.

end of the bar; if the current is circulating around the bar (with relation to the position in which we are looking at it) in the direction in which the hands of a clock move, then the end at which we are looking is a south pole, and vice versa.

When a positive pole of a battery is placed to a line wire, the current is supposed to flow out on the line; when a negative pole of a battery is to the line, the current is supposed to flow in from the line. If the reader who is beginning the study of the polar duplex will bear this in mind, it will simplify the study considerably,

and it will be well to remember that when we have, say, 50 positive cells of battery at one end of the wire and 50 cells of positive battery to the line at the other end, there will be no flow of current on the line, as these batteries neutralize each other.

In Fig. 22 let us suppose that *B* is a bar of soft iron, bent into the shape shown, encircled by a coil of wire, also in manner shown, and that *M* is a strip of magnetized iron, freely suspended, with its

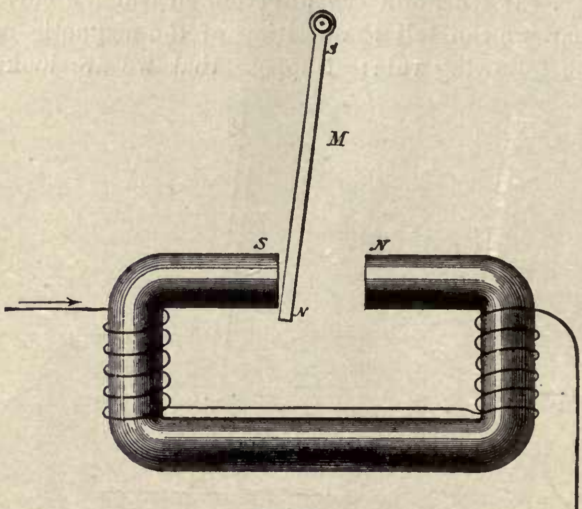


Fig. 23.

north pole *N* between the ends of the iron bar. If a current of electricity be sent through the wire in the direction indicated by the arrows, the bar will become a magnet with its poles as marked. Hence, as like poles repel and unlike poles of magnets attract each other, the north pole of the magnet *M* will be attracted to *S* and repelled from *N*.

Now if the direction of the current be reversed, as shown by the arrow in Fig. 23, it will of course traverse the coil and go around the bar in a direction opposite to that shown in Fig. 22. Consequently, as the polarity of the bar is determined by the direction of the current around it, its polarity will be changed, and the poles

will now be as marked in Fig. 23. Therefore the magnet *M* will now be repelled from its last position and attracted to the other side, as shown. Thus we can see that as often as we change the direction of the current around the bar, we change the position of the poles of the bar, and at the same time, by the alternate attraction and repulsion, change the position of the magnet *M* suspended between the poles of the bar. It follows that if we cause the magnet *M* to control a local circuit, and provide an instrument to reverse the direction of the current, we have the necessary conditions for a system of telegraphy, and this principle is taken advantage of in the polar duplex, by means of the polar relay and pole changer.

THE POLAR RELAY.

The polar relay is constructed with a view of complying with the above conditions.

When an iron bar is magnetized by electricity circulating around it, it is termed an electro-magnet.

Fig. 24 gives a front view of a polar relay.

P is a curved piece of steel, which is permanently magnetized to the polarity marked. *E M* is an electro-magnet, the core or bar of which is somewhat similar in shape to the bars shown in Figs. 22 and 23, but wound differentially. This electro-magnet is screwed firmly to the south pole of the permanent magnet. The armature is a soft iron strip or lever hinged at one end to the north pole of the permanent magnet *P*, as shown in dotted lines, its other end projecting between and beyond the poles of the electro-magnet *E M.*

Where there is no current traversing the coils of the electro-magnet *E M*, the *poles* of its core become, by induction, the south poles of the permanent magnet *P*. Likewise the outward end of the lever *M* has become and remains the north pole of the permanent magnet *P*. Thus the lever *M*, when adjusted in the center, will be attracted equally by either end of the electro-magnet, as both of its ends are, at present, south poles.

When a current is sent through one coil of the electro-magnet *E M*, the electro-magnetism thus generated in its core, being of greater strength, will overcome the magnetism induced by the permanent magnet *P*, and the poles will be established according to the direction of the current around the core. The polarity of the lever *M* will, however, remain constant, and it will be attracted

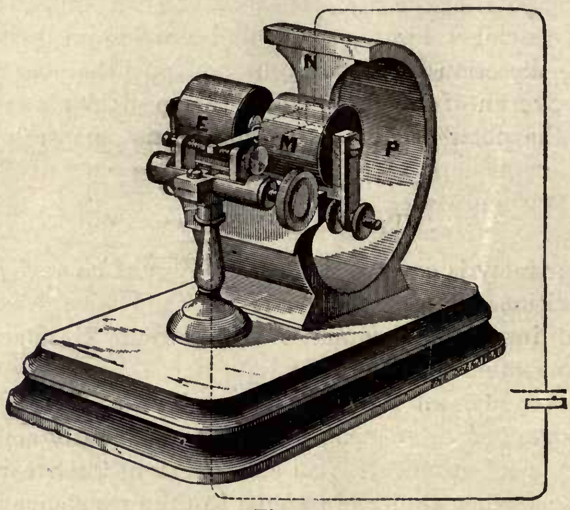


Fig. 24.

and repelled by the alternate changes of the polarity in the electro-magnet, and, as the lever is provided with a contact point to break and close the local circuit shown in the diagram, a signal will be recorded on the local sounder at each change of the direction of the current around the core of the electro-magnet.

CHAPTER VI.

THE POLAR DUPLEX.

Fig. 25 is a diagram of the polar duplex set up at both ends.

For the purpose of illustration, we shall speak of the currents as circulating around the cores of the polar relays in a direction from right to left, or left to right, as the case may be; and, in the diagram, the preponderance of the current in either of those directions may be supposed to have magnetized the cores to the polarities marked.

A and *A′* are pole changers, *R* and *R′* are polar relays. *B* is a battery having, in the present position of pole changer *A*, its positive pole to line. *B′* is another battery having, in present position of pole changer *A′*, its negative pole to line. *C* and *C′* are condensers adjusted to give a static discharge equal to that from the line at the moment of the change of the battery polarities, and thus prevent a "kick" similar to that mentioned in the Stearns duplex. *H* and *H′* are rheostats adjusted to equal the resistance of the line wire. The electro-magnets of the polar relays *R* and *R′* are wound differentially. Hence a current from battery *B* (supposing for the moment that there is no battery at the distant end) will divide at the split *S* in two equal portions, each portion we shall say with a strength of 2, as explained in the Stearns duplex, one portion going to the ground through the line, and the other to the ground through the rheostat *H*, in opposite directions around the core of the relay *R*, producing no magnetism in it.

If now we suppose that battery *B′* be placed in the circuit, with its negative pole to the line, it will give the current traversing the line coil *a* of *R*, from left to right, a strength of 4, and this additional strength overcoming the strength of 2 in coil *b* will magnetize the core of *R* to the polarity marked, consequently the

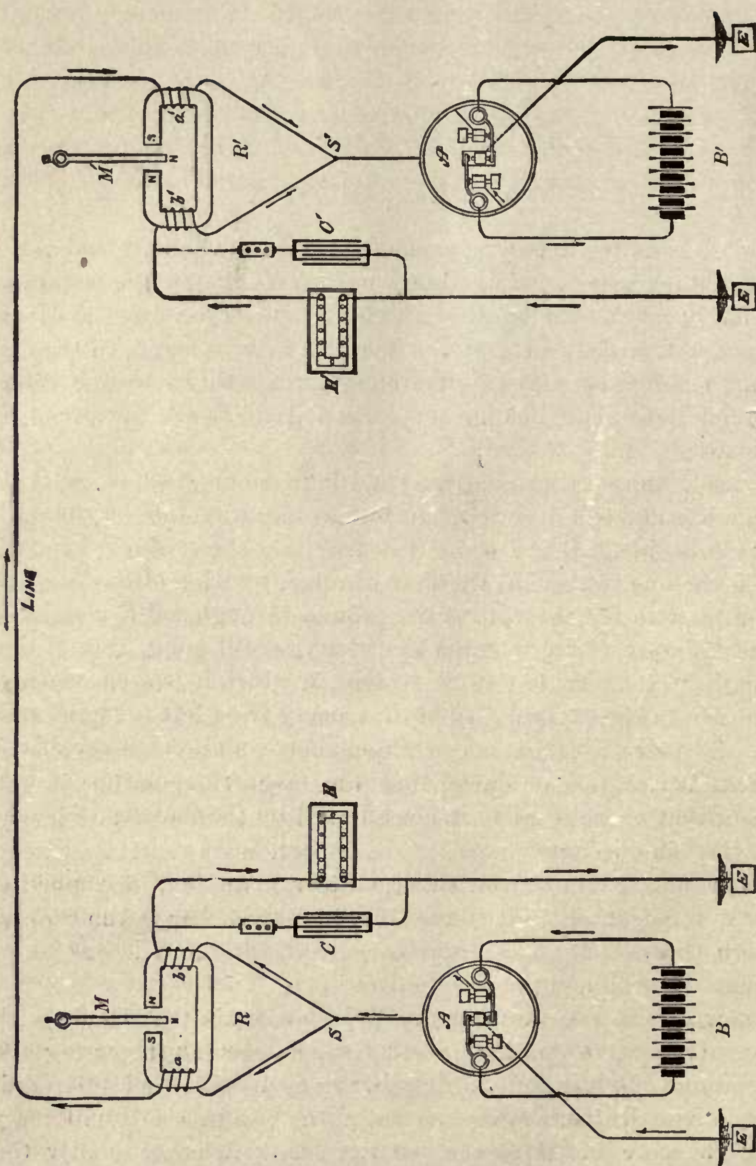


Fig. 25.—DIAGRAM OF POLAR DUPLEX.

outward end of lever *M* being a north pole will be attracted to *S* and repelled from *N*. A somewhat similar effect takes place in relay *R′*. The positive current from *B* is augmented by the negative current of *B′* and thus there is a current of a strength of four traversing coil *a′* and going around the core of *R′* from right to left, also magnetizing it to the polarity marked and attracting the lever *M.′*

Now, if while the negative pole of battery *B′* is still to the line, we change the polarity of the home battery *B* by opening the pole changer *A*, what will be the effect on the home relay *R?* It should be nothing. Let us see, and here the reader is recommended to draw for himself diagrams corresponding to the consequent changes. This change puts the negative pole of battery *B* to the line. Thus batteries *B* and *B′* are now opposed to each other, and, being of equal strength, there is no flow of current through the line coil *a* of relay *R*, but as the direction of the current of *B* is changed, and while it is true that there is now no current on the line coil of *R*, there is a current with a strength of 2 flowing in from the rheostat to the ground through coil *b*, and, as it thus flows, we may see that the electricity is still going around the core of *R*, in a direction similar to that in which it was circulating before the change of polarity at *B*, namely from left to right, and hence the polarity of the core is unchanged, and the lever *M* remains as before. This shows that the magnetic polarity of the home *differential* polar relay is not affected by the changes of polarity in the home battery.

Let us now examine the effect on the relay *R* of a change of polarity in battery *B′*. It should reverse the magnetic polarity of the core of relay *R*. The negative pole of battery *B′* has been to the line. It will now be the positive pole. Let *B* have positive pole to line as in Fig. 25. In this position, the positive pole of *B* now neutralizes the positive pole of *B*, and therefore there is no flow through the line coil *a*, but there is a current of a strength of 2 now flowing through the rheostat *H* to the ground through the coil *b*, and as this current is circulating around the core in an oppo-

site direction to that in which the previous magnetizing current had been flowing, namely from right to left, the polarity of *R* is now changed, whereby the lever *M* is repelled from its former position and attracted to the other end of the core. Thus we observe that the relay *R* responds to every change of the polarity at the distant end of the line, regardless of the polarity of the home battery *B*. It is needless to add that the relay *R'* will in a like manner respond to every change of polarity in battery *B*. Such being the case, we may simultaneously change the polarity at each end as frequently as desired, and the various signals will be recorded appropriately.

There is probably nothing in the operation of the polar duplex or quadruplex more difficult of comprehension to the beginner than the effect produced by the placing of similar poles of batteries against each other. For instance, if we take a battery of 100 cells at one end of a line and one of 50 cells at the other end, and place the positive poles of each battery to the line, there will be, roughly speaking, a strength on the line equal to that from a single battery of 50 cells, and the beginner is generally at a loss to understand what becomes of the strength of the remaining 100 cells. To tell him that 50 cells at one end are neutralized by 50 at the other end is not always satisfactory.

Perhaps the following homely illustration will make it somewhat plainer:

Let us imagine a railway train with a locomotive at each end of the train, each locomotive to have a strength of 50. If we oppose the strength of these engines against each other, we know that the train will not move. If now we bring another locomotive having also a strength of 50 and place it at one of the ends, the train will now move, but urged only by a strength in all of 50, although there is a locomotive force of 150 being exerted on the train. In other words, the power of two of the locomotives is consumed, one in opposing another of equal power, as in the case of the battery referred to.

We may indeed use the same homely illustration in a variety of ways to show the action of electricity on a wire.

We have heretofore spoken of the *current* or *flow* of electricity when we have meant to signify the *direction* in which the electricity *acts*. Thus, we have said that when the positive pole of a battery is placed to the line its action is, invariably, toward the line, as shown by a galvanometer, and the action of a negative pole when placed to the line is as invariably inward from the line.

Now, if we say that when a locomotive is pushing the train it is exerting a positive strength, and when it is pulling the train that it is exerting a negative strength, it is easy to understand that if we cause the engine at one end of the train to exert a positive and the one at the other a negative strength upon the train, there will be the full effect of two engines acting upon the train in the same direction, and the train will move accordingly.

On the contrary, if we cause both to exert a positive strength, or both to exert a negative strength upon the train, that is to say, if we cause them both to push or both to pull the train, it will not move.

Thus it is, practically, with electric batteries at each end of a wire, with regard to their effect on electro-magnets. If we place their positive poles to the line, the action of each is toward the line and no effect is produced. If we place their negative poles to the line, their action is inward from the line and no result follows; but if we put the negative pole of the battery to the line at one end and the positive pole at the other end, the strength of both is now virtually being exerted in the same direction on the wire and the strength of the two batteries is obtained.

In addition to the weight of the train which the engines have to move, they also have to use part of their strength in moving themselves.

The resistance which a battery has to overcome in its own elements and which is called its internal resistance, as before stated, may be likened to the weight of the engine. Thus the lower the internal resistance of a battery can be made without reducing its electro-motive force, the greater will be the resultant strength upon a given wire.

CHAPTER VII.

THE QUADRUPLEX.

Having studied the principles upon which the Stearns and polar duplexes are operated, it will perhaps render the study of the quadruplex less complex if we first examine separately the modifications necessary to the combination of these duplex principles in the quadruplex.

We have seen that the Stearns duplex is operated primarily upon two conditions, namely, battery to the line and no battery to the line. Consequently, there are intervals in the working of this duplex when there is no current on the line. It will at once suggest itself to the student that such a condition as this on the polar duplex (which is operated, not by a withdrawal of the current at any time, but by a change in its direction,) would render it inoperative. Therefore, if we are to combine these two principles, we must in some way preserve at all times a current on the wire to insure the working of the polar system.

The manner in which this is accomplished will be shown in the description of Figs. 27 and 28.

We have seen also that the polar relay in the polar duplex system is actuated by the reversals of polarity, and that the neutral relay in the Stearns duplex is attracted by a current of either polarity.

The following illustration will explain how these different results are obtained on the same wire at the same time, as they are in the quadruplex system, without interfering with each other.

In Fig. 26 we have a single wire encircling the cores of a neutral and a polarized relay in such a manner that a positive current with, we will again assume, a strength of 2 from battery *C* will pass around their cores in a direction tending to magnetize them

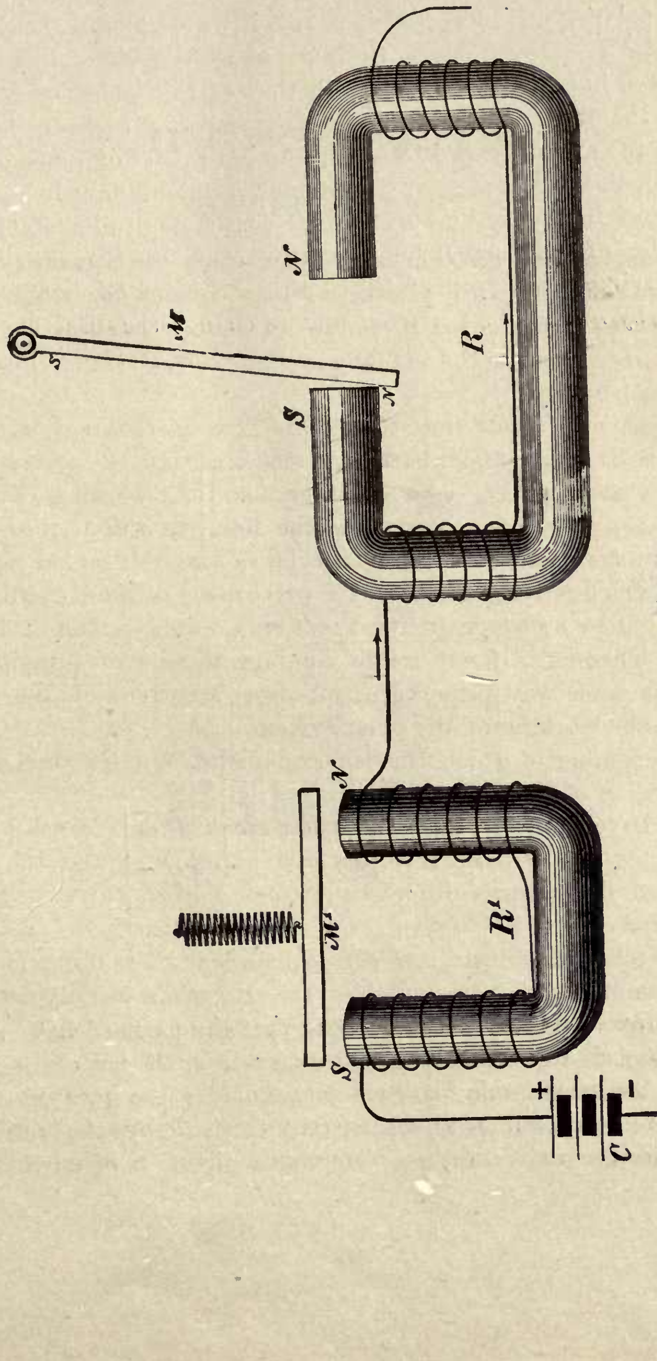


Fig. 26.

to the polarity marked—that is to say, if we are looking at the ends marked *S* (the south pole), the current will be circulating around the cores in a direction similar to that of the hands of a watch. Hence the north pole of lever *M* is attracted to *S* and repelled from *N*, and the armature *M′* is attracted to both poles of its magnet, as in the ordinary Morse relay or sounder. Let us now increase the tension of the retractile spring of *M′* just enough to overcome the attraction of the magnetism generated in *R′* by the existing current having a strength of 2; so that *M′* is withdrawn from *R′*. If now, by means of a pole changer, we change the direction of the

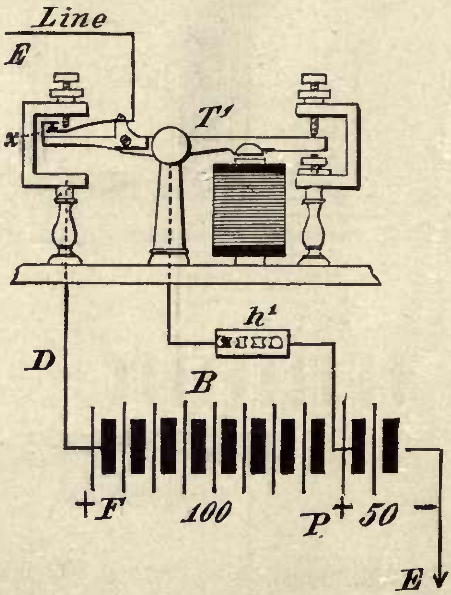


Fig. 27.

current from battery *C*, we shall find that the poles of both relays have changed, and that the armature or lever *M* has changed its position because of this; but we find that the armature *M′* of the neutral relay is unmoved, being still retained by the retractile spring, for the reason that, although the direction of current has

changed, its strength has not, and consequently the strength of the magnetism of *R′* has not been augmented.

Again referring to Fig. 26. If now we increase the strength of the current from 2 to say 4, without changing the direction of the current, we find that the increased magnetism in relay *R′* has attracted armature *M′*, but the only effect produced on the lever *M*, by the additional strength of current, is that it is more strongly attracted to *S*, and repelled from *N*.

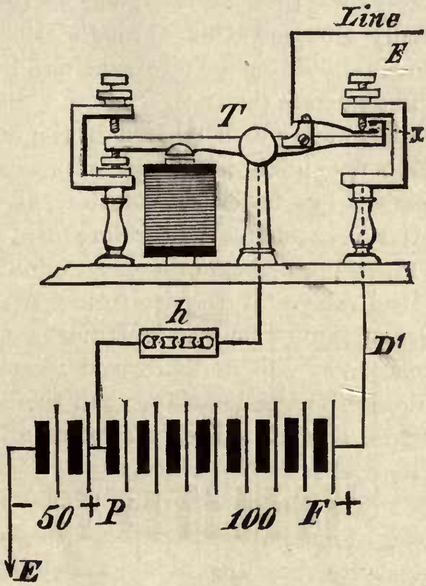


Fig. 28.

To carry the illustration one point further. If, while the strength of 4 is on the line, we change the direction of the current, we find that the lever *M* has again been affected, and that it has changed its position, while the armature *M′* is unmoved for the reason before given.

The foregoing embodies the manner in which the two main principles of the duplexes are combined in the quadruplex.

In our study of the Stearns duplex we learned that the function

of the transmitter was to alternately place the line to the battery and to the ground. In the quadruplex system its function is to alternately place the whole battery and a small portion of the battery to the line, in the manner hereafter described.

The armature of the neutral relay in the quadruplex is adjusted so that the smaller portion of the distant battery will have no practical effect upon it, and as this smaller portion of the current is reduced to the lowest point compatible with the effective working of the polar relay, it follows that, as the polar relay is designed to work uninterruptedly and smoothly through all changes in the strength of current, it should be a more sensitive instrument than the neutral relay, and such is the case

As sensitiveness is not so much desired in the neutral relay, its core is made very short, and it is wound with coarser wire than the polar relay, hence it has fewer convolutions of wire around its cores than the latter instrument. Therefore a given strength of current will have much more magnetic effect upon the polar relay than upon the neutral relay. But apart from the above noted differences in the construction of the two instruments the fact that the armature of the polar relay aids in its own movements is an important factor in rendering it more sensitive than the neutral relay.

The usual resistance of each coil of the polar relay is about 400 ohms, that of the neutral relay 200 ohms.

Figs. 27 and 28 show the manner in which the transmitter changes the strength of current on the wire. In the figures the instruments unnecessary to show this action are omitted.

Fig. 27 shows a wire running from the earth to the negative pole of battery *B*. There is also another wire from one of the positive cells of the battery which runs from *P* to the bar of the transmitter, which is represented as open Another wire is led from the positive end of the battery to the post *D* of the transmitter, and the line wire is connected as heretofore to the tongue of that instrument. The same connections occur in Fig. 28. In Fig. 27, if we follow the circuit through the full battery to post *D*, we can see that it leads to an open point near *X*, so that no current can

pass. On the contrary, if we follow the wire, which taps the battery at *P*, we may see that there is here a route for the current through the bar to the tongue of the transmitter, and thence to the line; but in this case it is plain that that portion of the battery between *P* and *F* is cut off, and thus only a small portion of the battery is placed to the line, hence the neutral or No. 2 relay at distant end will not have attracted its armature. Referring now to Fig. 28, the transmitter is shown as closed. The figure shows that the bar of the transmitter has broken contact with the tongue at *X*, but instead the tongue has made contact with the post *D′*. Thus the full battery is now placed to the line, and the armature of neutral relay at distant end will be attracted to the core. Thus, as often as the transmitter is opened or closed, the full battery, or only a portion thereof, will be placed to the line, but in either case there must always be sufficient current left on the line to operate the polar relays.

Fig. 29 shows the theoretical manner in which the various principles that we have been considering in the duplexes, etc., are grouped to produce the Edison quadruplex.

P and *P′* are pole changers, *T* and *T′* are transmitters, *N* and *N′* are neutral relays, *R* and *R′* are polarized relays. The manner in which the relays are wound in the figure is not the precise method adopted in actual practice, but the result is the same. We have chosen the manner of winding shown in the diagram with a view to making the action of the current on the cores of the electro-magnets easier of comprehension.

The figure shows the quadruplex theoretically set up at both ends, namely *A* and *B*.

At *A* the keys of both sides are supposed to be closed, at *B* open.

It might be supposed that having discovered the foregoing principles of electricity and magnetism, it only remained for the inventor to manufacture and arrange the instruments necessary to produce the increase and decrease of current and the changes of polarity, with instruments to respond to those changes, when he

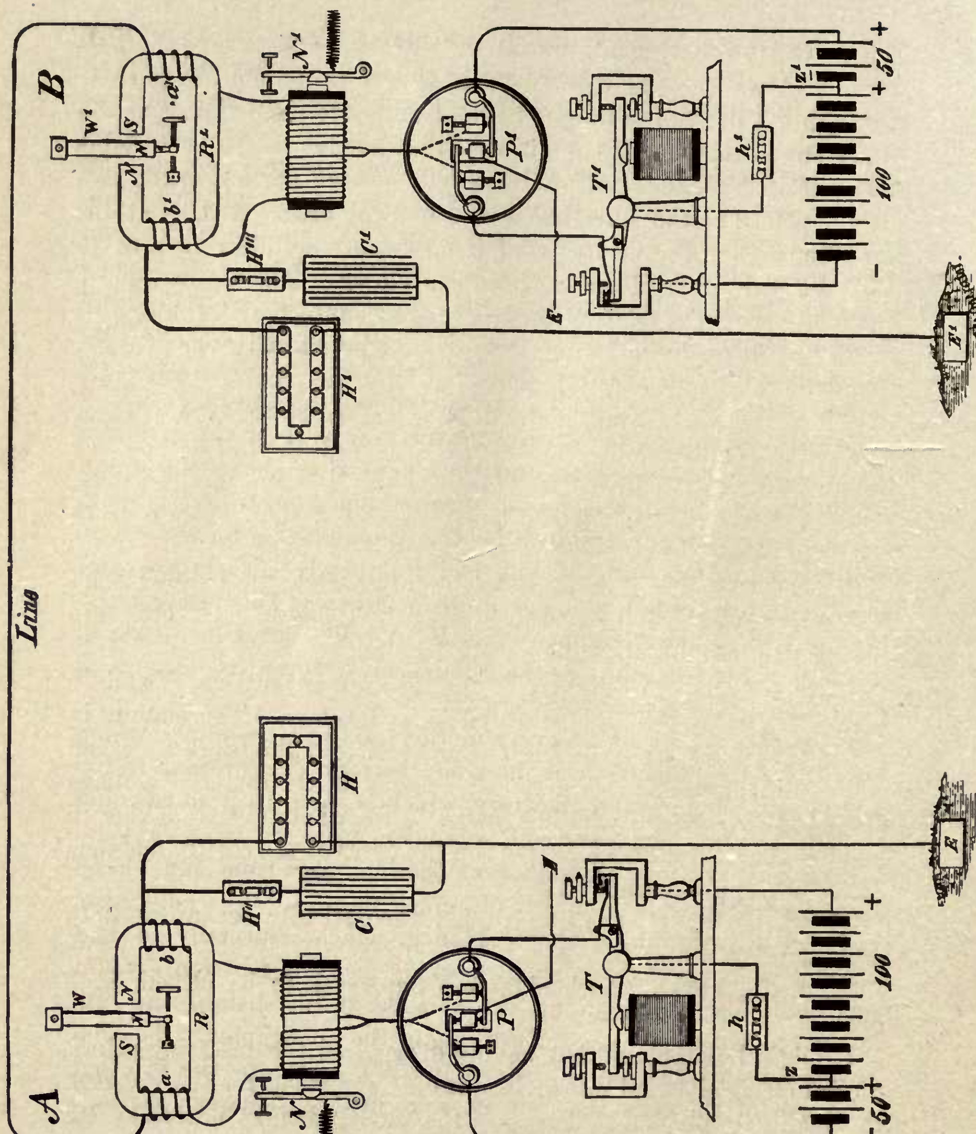


Fig. 29.—THEORETICAL DIAGRAM OF QUADRUPLEX.

would have a successful working quadruplex system, and probably this was the conclusion arrived at by many inventors and experimenters, but actual experience taught them that more than this was required. For instance, it was found, as in the duplexes, that between each change of polarity of the home battery the line on long circuits gave back a return or static discharge, which, by momentarily charging the cores of the relay with opposite magnetism, produced a click in the home relays, which rendered the signals from the distant end unreadable. Hence it was necessary to insert in the balancing wire between the rheostats and the relays a condenser (C and C' as in figure), which would accumulate a quantity of electricity equal to that accumulated on the line, and which would also discharge itself during the interval between the reversals of the poles of the batteries, and thus neutralize the effect of the line discharge. This was found effectual on comparatively short circuits, but on longer circuits it became apparent that the condenser discharged itself before the line had completely discharged, and thus the result desired was not quite attained. This necessitated the insertion of the resistance coils H'' and H''' between the artificial wire of the rheostat and the condenser, to retard the discharge of the latter, which proved successful.

It was also seen that at every motion of the transmitter which cuts off the larger portion of the home battery, the internal resistance of said portion of the battery, which is equal to from two and one half, to three ohms per cell, was taken from the wire, thus deducting from the total resistance of the line, say, from 100 to 500 ohms, according to the number of cells cut off. This would have produced a variation in the resistance, which, especially in bad weather, when there was a small working margin of current, would more than likely, by making the balance at the distant end unsteady, prevent the successful working of the quadruplex. To compensate for this, resistance coils (h and h'), equal to the internal resistance of the cells thus cut off, were inserted between the taps Z and Z' and the bars of the transmitters.

Another obstacle to the working of the quadruplex was also en-

countered. It was found that while the full battery was to the line (as at A in the figure, and the armature of neutral relay N' at distant end B was thus attracted to its magnet), if the polarity at station A was changed, thereby, as we have seen, for an instant taking off the battery at A, from the line, at that instant the retractile spring of the neutral relay N' would tend to withdraw the armature from the magnet, thus making a false "clip," and breaking up the regular signals. To obviate this trouble the local contact of the neutral relay is placed on the back stop, and a repeating sounder is in many cases also added to the local circuit, as is shown in cut (Fig. 30). The instant when the battery is cut off from the line is, however, of so short duration that the neutral relay has apparently not time to become entirely demagnetized, so that it regains its maximum magnetism and re-attracts its armature before the latter has made a firm contact on the back stroke, and hence the repeating sounder is not fully charged, consequently its armature is not sufficiently affected by the false signals to interfere with the regular sounder, which is operated by this armature, and thus the signals intended for the neutral relay, although undoubtedly mutilated in the course of transmission while the polar side is in operation, are received, by means of the above arrangement, unbroken, and on the front stop of the regular local sounder. When the repeating sounder is dispensed with, as it is now on many circuits, the connections are so arranged at the distant end that in reality the transmitter sends out the signals on the "back stroke," but as the local contact point of the neutral relay is placed, as before stated, on the back stop, the receiving operator receives the signals as usual.

It may be asked, why is not the polarized relay affected in the same manner at the instant of change of polarity of the distant battery? In fact it is, that is to say, it also partly loses the magnetism due to the distant battery, but at that instant the permanent magnetism of the polarized relay comes into operation, and, as has been shown, as the ends of the core of the electro-magnet of the polarized relay are in that case both south poles, the north pole of

its armature will be retained in its present position until the actual change of polarity ensues. But aside from this, there would be no tendency on the part of the armature of the polarized relay to leave its existing position, owing to the fact that its inertia would be sufficient to keep it where last placed; it being, as we have said, the retractile spring of the neutral relay which tends to draw it away at the time referred to.

Even after all these defects were discovered and remedied the quadruplex was not yet a success, and it was not until after many months of actual working and experiment that the modifications of the instruments first used, which have brought the system to its present state of usefulness, were invented and applied.

The polar side of the quadruplex is frequently called the No. 1 side; and the increase and decrease of strength side, the No. 2 side.

The polar relay and neutral relay are also spoken of as the No. 1 and No. 2 relay, respectively.

When the compound polarized relay was used on the No. 2 side of the quadruplex it was found that a condenser inserted between that relay and the polar relay, by absorbing or counteracting the extra currents generated by the demagnetization of the cores of the relay, steadied that relay somewhat during the changes of polarity, but as the utility of that condenser seems to have ceased with the introduction of the short core relay, and as it is now dispensed with entirely on many circuits, we have not included it in the diagrams.

There now remains but little to be said as to the working of the quadruplex if the reader has followed us by the different stages that have led up to this point.

We shall, however, for the benefit of the beginner, trace the course of the circuit in Fig. 29. Beginning at *E*, station *A*, the circuit is led to the bar of the pole changer, thence *via* the upper tongue of the same to the negative pole of the battery at *A*, through the entire battery to the post and tongue of the transmitter, to the lower tongue of the pole changer and thence to the disc thereof. Here the circuit is divided, one portion going through the neutral

relay, the polar relay, and to the line and to the ground at distant end *B*. The other portion of the circuit goes through the neutral and polar relays and through the rheostat *H* to the ground.

Beginning at *E*, station *B*, the circuit is led to the bar of the pole changer, thence to the lower tongue of that instrument, to the positive pole of battery at *B*, through the small end of this battery to *Z'*, thence to the bar of *T'*, and *via* the tongue of *T'* to the upper tongue of *P'* and to the disc thereof, where the current divides as at *A*.

In the present positions of the transmitters and pole changers at both ends, the polar relays and neutral relays are attracted or withdrawn, as shown. That such results are produced by these conditions is well known to all who have had practical acquaintance with the working of the quadruplex, but for the information of those who wish to trace the question we shall endeavor to analyze one or two of the many combinations that occur on the quadruplex, which could not occur on either the Stearns or the polar duplex alone, promising the beginner, however, that it may require considerable study on his part to thoroughly understand them. We will suppose that the small ends of both batteries consist of 50 cells and the large ends 100 cells each, making the total of each battery 150 cells. Thus, as the full battery at *A* is to the line with its positive pole, and as it is augmented by 50 cells from the negative pole of that at *B*, there is virtually a strength from 200 cells flowing through the coil *a* of *R*, from left to right to the line and a strength from 150 cells flowing through coil *b* from right to left to the rheostat. (It is of course understood that we speak of a strength of 200 cells on the line merely for purpose of illustration.) This attracts, as we see, the armature of the neutral relay *N'* at *B*, and the negative pole of battery at *B* being to the line, the armature of *R* is as placed. Let us now close the pole changer *P'* at *B*. This places 50 cells of positive polarity to the line at this point *B*, and these 50 cells oppose and neutralize 50 positive cells of battery at *A*, making the total strength of current now on the line equal to 100 cells. This now leaves, therefore, a strength of 100 cells flowing through coil *a* of

the polar relay *R* to line from left to right, while there is now a strength of 150 cells flowing from the battery at *A* through the coil *b* of the polar relay to rheostat from right to left. This leaves a preponderance of current flowing in the latter direction, and, consequently, the polarity of the polar relay *R* is reversed, and its armature changes its position.

This position of the pole changer at *B*, as we saw, reduces the strength of current coming from battery at *A* to 100 cells. Why, therefore, does not the retractile spring withdraw the armature of *N'*, which we saw was held to the armature by the full battery of *A*, viz., 150 cells being to the line? It is because there is now a strength of 50 cells from the positive pole at *B* going through the neutral relay *N'* to the rheostat and ground, and this strength of 50 cells, owing to the manner in which the coils are wound, is circulating around the core of the relay in the same direction as that of the current of 100 cells strength from *A*, thereby still preserving a strength of 150 cells on neutral relay *M'*, and of course this accounts for the fact that its armature remains attracted. There are many such combinations continually occurring on the quadruplex, which at first sight would seem to be enough to entirely prevent the working of the system, but an analysis of each combination will prove, what is known to be the case, that they do not so prevent.

In studying the combinations that occur on these multiplex systems, it should be remembered by the beginner that the currents which flow to or from the rheostat, or artificial wire, are always dependent on the home battery. If, for instance, 50 cells of positive polarity be placed to the line from battery at *B* in Fig. 29, a positive current of 50-cells strength will flow to the ground through the rheostat, even though a positive battery of 150 cells should be opposed to the same battery at the distant end, *A*. In other words, the wire through the rheostat may be considered as a separate wire, excepting that it is led through one coil of the various differential relays.

Fig. 30 is a diagram showing the actual connections at one end of a quadruplex system. The polar relay and the neutral relay are

shown by the bare coils. The repeating sounder previously mentioned adjoins the neutral relay. *Q* is the resistance to compensate for that portion of the battery which is cut out when the small end of the battery is to the line. The coil *G* in the rheostat *R* is the resistance—equal to the internal resistance of the entire battery—which is placed in the circuit when the wire is grounded for a balance. The wire is grounded for this purpose by turning the three-button switch *B* to the right. It will be noticed that this action cuts off the battery, the pole changer and transmitter.

Q′ is the resistance placed between the condenser and rheostat wire on long circuits, for reasons already explained.

The route of the circuit in the present position of the pole changer and transmitter is traced by the figures 1, 2, 3, 4, etc., up to 13, where the circuit divides, and letters then show the route to ground through the rheostat.

It may be stated in passing that there has been no special attempt made in these diagrams to show the instruments in their actual relations to each other as to size, the main idea being to present the instruments in the clearest and simplest position. Thus the rheostat box is shown as apparently smaller than the transmitter, whereas, in reality, as we all know, it is several times larger.

Balancing the Quadruplex.

To balance a quadruplex, ask the distant station to ground for you. In doing so he cuts out his pole changer and entire battery, as may be seen in the diagram of the complete quadruplex with connections. It will also be seen that in grounding he interposes a resistance equal to the internal resistance of his entire battery, otherwise when he again cuts in his battery your balance would be several hundred ohms too low, according to the size of his battery. You now also ground. Now the wire is without battery at either end. Then adjust the armature of the polarized relay so that it will stay on whichever side it is placed. Now cut in your full battery and insert or withdraw plugs from your rheostat until the armature of the polarized relay again remains on whichever side placed,

this showing that an equal strength of electricity is flowing in opposite directions around the core of the relay, as no magnetic effect is produced, and proving that the resistances of the line and rheostat are equal. Now open and close the pole changer and note the action of the polar relay. If it responds clearly to each motion of your pole changer, you either have too much or not enough discharge from your condenser. Therefore adjust your condenser until its discharge is sufficient to neutralize the static discharge from the line, which will be shown by the failure of the polarized relay now to respond to the movement of the pole changer.

The polar duplex is balanced in the same manner as the quadruplex. The Stearns duplex is balanced by asking the distant station to open his key, which is virtually asking him to "ground." Then dot on your own key and adjust your rheostat and condenser until your relay remains passive under the movements of your transmitter.

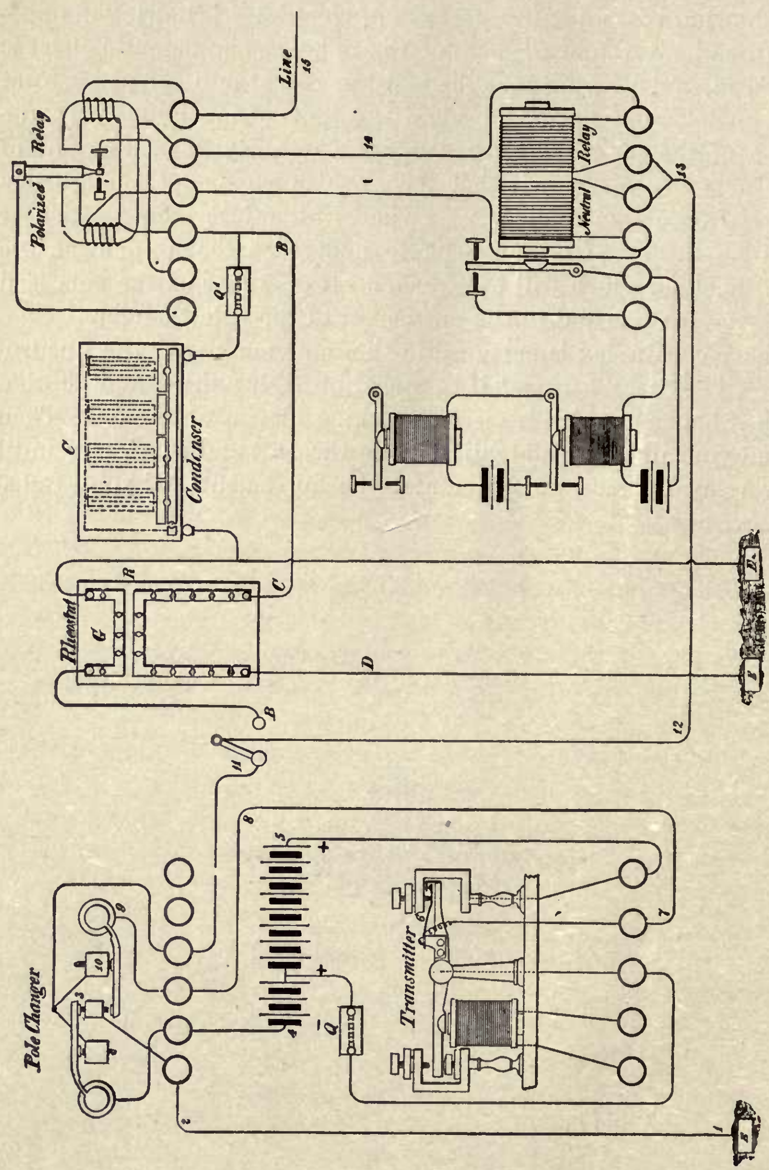


Fig. 30.—DIAGRAM OF QUADRUPLEX CONNECTIONS.

CHAPTER VIII.

The Dynamo-Electric Machine in Relation to the Quadruplex.

BY WM. MAYER, JR.

Upon the introduction of the dynamo-electric machines into the Western Union building as a means of supplying electro-motive force, it was found necessary, if this source of supply was to be availed of in the working of the polar duplex and the quadruplex systems, to alter considerably the arrangement of the instruments used in the working of those systems by the gravity battery.

Before proceeding to describe these alterations it will perhaps be well to interpose the following description of the manner in which the dynamo machines supply the electro-motive force to the various wires. The description will, I think, tend to make plainer some of the statements hereafter made.

I may state that this account of the dynamo machines is taken almost verbatim from an article on the Western Union building, written by me some time ago, for *The Electrical World.*

The electro-motive force for the wires leaving the Western Union main office is furnished by dynamo-electric machines, of which there are fifteen on the battery floor, in series of five machines. Thus there are three series. Two of these series are kept in operation day and night, the other series being reserved for emergencies or to allow of necessary repairs. The motive power for these machines is supplied by three safety steam-power engines of six horse-power each, which derive their steam from boilers in the sub-cellar. Of these series or gangs of five machines, one machine is used to generate a magnetic field for itself and the four other machines. It also determines the polarity of the series according to the direction of its current around the field-magnets of the other machines. One of the active series supplies negative, the other positive, polarity to the wires.

The polarity of the spare series may easily be changed to positive or negative by means of a switch arranged for the purpose in the battery room.

Four grades of potential are furnished from each series of these machines, in the manner hereafter described.

Artificial resistances, equal to three ohms per volt, composed of coils of German silver wire wound on cylinders of prepared plaster of paris, are interposed between each machine and every wire leaving the switch, as shown in the engraving. Thus the resistance of each coil interposed between the first potential and the wires is about 200 ohms; between the second potential and wires, 400 ohms; between the third potential and wires, 600 ohms, and between the fourth potential and wires, 800 ohms. These coils serve to diminish the intensity of the dynamo current, thereby obviating sparks, and to prevent, in a measure, the burning of instruments in case of the short circuiting of a wire. The first, second, and third potentials are conducted to the main switch, the first and second potentials only to the city line and Long Island switch.

The fourth potential is used principally to supply very long quadruplex circuits, such as those to Bangor, Me.; Lynchburg, Va., etc.

Wires having an average resistance of about 3,000 ohms are supplied from the first potential. Those having an average resistance of about 5,500, from the second potential. The third potential is mainly used for duplex and quadruplex circuits. The New York City, Brooklyn, and Jersey City wires, being generally of low resistance, are also supplied from the first potential; but the resistances of those wires are increased by means of resistance plugs, inserted at the switch in their circuits, to an average resistance of from 3,000 to 4,000 ohms.

The illustration, Fig. 31, gives a top view of one series of the dynamo machines, showing the manner in which the several potentials are derived and the method of interposing the artificial resistance coils previously mentioned.

A, *B*, *C*, *D*, and *E* are the five dynamo machines of one series. *A* is the feeder which furnishes the magnetic fields for itself and the

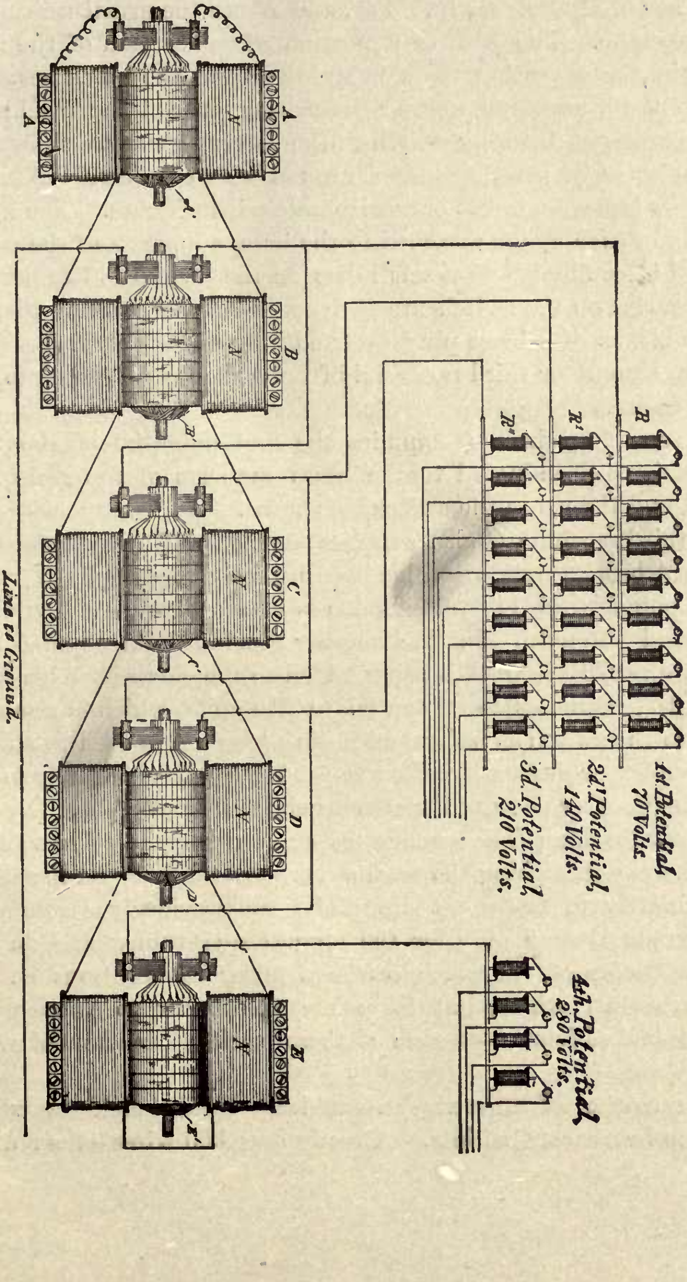

Line to Ground.
1st. Potential,
70 Volts.
2d. Potential,
140 Volts.
3d. Potential,
210 Volts.
4th. Potential,
280 Volts.

Fig. 31.

four other machines. *A′*, *B′*, *C′*, *D′*, and *E′* are the armature coils of each machine. The rear of a portion of one section of the main switch in the operating room is shown above the machines. To simplify the illustration, neither the belting gear of the machinery nor the polarity changing switch in the battery room are shown.

The plaster of paris cylinders, around which the artificial resistance coils are wound, rest on horizontal strips of brass. The lower terminal of each coil is attached to the brass support and the upper terminal is conducted to a small disc on the switch. The perpendicular strips on the switch are each connected to one line wire, so that by means of a brass plug inserted between a disc and a strip the first, second, or third potential of current may be placed to the line as desired.

The second machine *B* supplies the first potential of about 70 volts, which is conducted to the brass supports of the resistance coils *R*, and thence to the switch, as shown.

The third machine *C* also supplies an electro-motive force of 70 volts, which being reinforced by the 70 volts generated by *B*, raises the net potential to 140 volts, which is conducted to the switch as the second potential. In like manner the fourth machine *D* supplies another 70 volts. This being added to the electro-motive force of *B* and *C*, increases the potential to 210 volts, which is also conducted to the switch as before, excepting where it is used to supply a quadruplex or duplex circuit, when it is conducted directly to the instruments, after passing through special resistance coils.

The last machine *E* also generates an electro-motive force of 70 volts, thereby increasing the total electro-motive force of the series approximately to 280 volts potential. As previously stated, this fourth grade is used only for the longest quadruplex and duplex circuits. Some of the machines have fewer convolutions on the armatures than others, but these are run faster to compensate. The internal resistance of each of these machines is about $\frac{1}{8}$ of an ohm.

The quantity of current generated by these machines would appear to be almost limitless. Already over 300 wires of an aver-

age resistance of about 3,000 ohms are supplied from the first potential without any perceptible diminution of the current or appreciable effect on the working of the machine, hence the great economy of the system, of which Mr. Stephen D. Field is the inventor.

I have said that upon the introduction of these dynamo machines into the Western Union building it was necessary to alter somewhat the connections and arrangements of the quadruplex, etc. This was owing to the fact, that as the dynamo machines are run in two series, one supplying positive and the other negative polarity, it is impracticable to tap a series at each end for change of polarity, as in the gravity batteries; and as each machine of a series furnishes a certain electro-motive force, about 70 volts, it was likewise impossible to regulate the small and long ends of the battery at will, as is done with the gravity cells. These difficulties were overcome: firstly, by changing the connections of the pole changer so that at every alternate motion of its lever it drew from first one series of dynamos, and then another, thus obtaining the necessary changes of polarity; and, secondly, by connecting the transmitter so that in one position of its lever it allows the full current to go to the line; while in the other the current is forced to pass through an added resistance before reaching the line, and is also given another and generally a shorter route to the earth, in the manner hereafter explained, so that the current passing to the line is greatly weakened.

The same practical result is obtained by this device as by the cutting off of a portion of the battery, namely, the current on the line is increased or decreased at each movement of the transmitter.

In one case the strength of current is decreased by a reduction of the electro-motive force, while in the other case, as we shall discover, the electro-motive force remains constant, but the circuit is varied.

The retractile spring of the neutral or No. 2 relay is therefore so adjusted that it withdraws the armature from the magnet when the combination of the added resistance and the extra route to the ground is in operation, but when this combination is inoperative

the consequent increased strength of current going to the line attracts the armature precisely as when in the gravity battery system the entire battery is placed to the line.

In a former part of this book it has been stated that the strength of current on any two wires supplied from the same battery will be the same on each wire, provided the resistances of the wires are equal. This is equally true if twenty or more wires of equal resistance are attached to the same battery, and is in accordance with the following law of electricity:

"*The relative strengths of current in the branches of a divided circuit will be inversely proportional to their resistances.*" For example, if we have a circuit divided into, say, two branches, the resistance of one being 12 ohms and the other 6 ohms, twice as much of the current will flow through the branch of 6 ohms as through the one of 12 ohms, because the latter route offers double the resistance to the current. Hence the route offering 6 ohms resistance will carry, in this case, two-thirds of the current, and the other route one-third. But there will not be as much total resistance offered to the current by the two routes together—that is to say, by their joint resistance—as by either route alone.

By joint resistance is meant the total resistance offered to a current supplied from one battery. For example, if two wires of 6 ohms each are led from one battery, the joint resistance of the two wires will be 3 ohms. Three wires of 6 ohms each will have a joint resistance of 2 ohms, etc.

This may be explained as follows: If we have a barrel filled with water and attach one faucet at the bottom a certain amount of resistance will be offered to the flow of water, another faucet will decrease this resistance, and still another faucet by providing an additional channel will yet further reduce the resistance.

The following is a simple rule for finding the joint resistance of wires in a circuit. Divide the product of the resistances of the two wires by their sum.

If there are more than two wires in the circuit, first find the joint resistance of any two of the wires. Then use this joint resistance

of the two wires as though it were the resistance of a single wire, and divide the product of said joint resistance and the resistance of the third wire by the sum of the same, which will give the joint resistance of the three wires. The joint resistance of the three wires may now be used to find the joint resistance of a fourth wire, and so on indefinitely.

The strength of a current of electricity, which is the amount of electricity *flowing* through a circuit in a given time, is equal to the number of volts of electro-motive force divided by the number of ohms of resistance in the entire circuit. This is in effect Ohm's law, viz.:

$$\text{Current} = \frac{\text{Electro-motive force,}}{\text{Resistance}} \text{ or } C = \frac{E}{R}$$

All of these laws are availed of in the operation of the quadruplex when the currents from the dynamo machines are used. Hence the necessity of a full understanding of them before proceeding to explain the latter system.

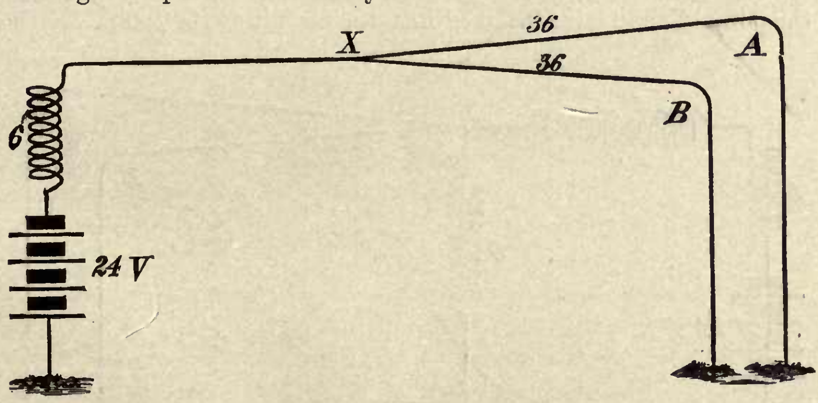


Fig. 32.

A preliminary example will now be given of the law of joint resistance, the law relating to the strength of currents in divided circuits, and Ohm's law.

In Fig. 32 let us suppose that up to the point *X*, there is a resistance of 6 ohms. At *X* the circuit divides into two branches, *A*

and *B*, each having 36 ohms resistance. By the rule given above, we find the joint resistance of these two branches, *A* and *B*, to be 18 ohms, which added to the 6 ohms resistance up to the point *X* makes the total resistance of the circuit 24 ohms. Supposing the electro-motive force to be 24 volts (a volt being the unit of electro-motive force), we find that as the strength of current on a circuit is equal to the electro-motive force divided by the total resistance, in this case it will be $\frac{24}{24} = 1$. Up to the point *X*, therefore, the strength of current on the wire is 1, but at this point the current divides equally between *A* and *B*, consequently on each of these branches the strength of current will be $\frac{1}{2}$. Now let us suppose that this strength is quite sufficient to magnetize strongly a relay at the distant end of *A* or *B*, and that in consequence its armature has been drawn to the cores of the magnet, as is the case, for instance, when the full battery is to the line in the Stearns duplex.

Now referring to Fig. 33.

We have interposed an additional resistance of 12 ohms before the point *X*, and have inserted into the circuit at that point another

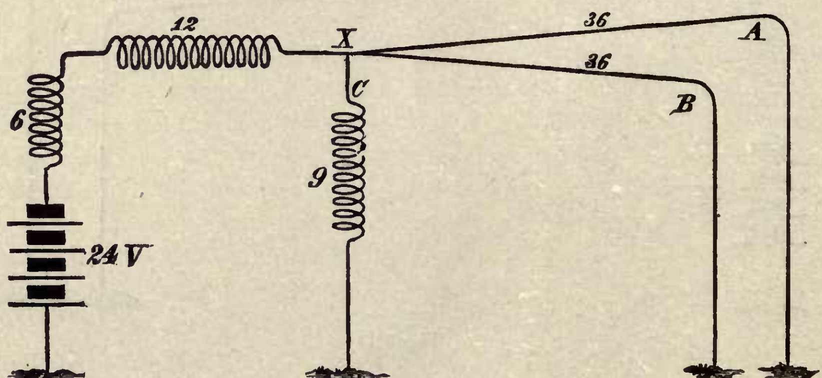


Fig. 33.

branch, *C*, having a resistance of only 9 ohms. In this case there are 18 ohms resistance before *X*. Now we require to find the joint resistance of *A*, *B*, and *C*. We have seen that the joint resistance

of A and B is 18 ohms, therefore, by the rule already quoted, when we find the joint resistance of 18 ohms and 9 ohms, which is 6 ohms, we have the joint resistance of the branches A, B, and C. These 6 ohms added to the 18 ohms inserted before X make a total resistance for this circuit of 24 ohms, the same as in Fig. 32 The strength of current, therefore, on this circuit up to X is also 1; but now this current has to be divided proportionately between A, B, and C. Hence, as the branch C offers only 9 ohms resistance while the joint resistance of A and B is 18 ohms, C will receive twice as much as both A and B. C will thus take two-thirds of the current, while one-third remains to be divided between A and B. This gives each of these branches a current of one-sixth, or only one-third of what it was in Fig. 31, which we will assume so weakens the magnetism of the relay at the distant end of A that the retractile spring withdraws the armature.

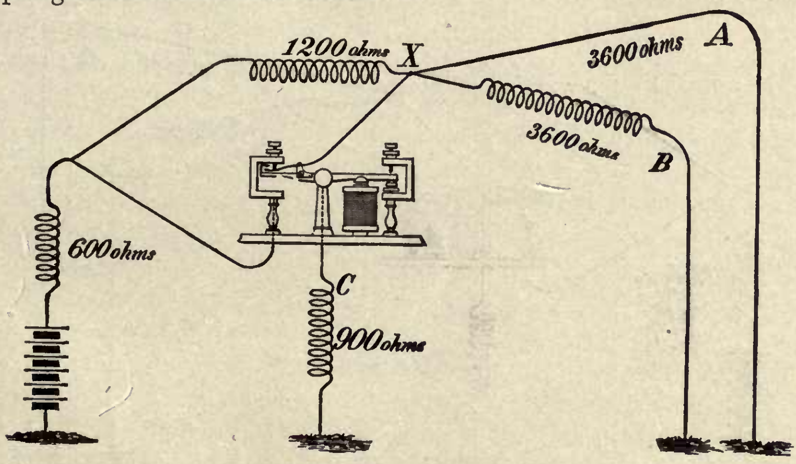


Fig. 34.

Now if we can arrange our connections so that at one position of the transmitter the circuit is virtually as shown in Fig. 32 while in the other position the circuit is as seen in Fig. 33, it is evident that we have the necessary arrangements for the increase and decrease side of the quadruplex. In other words, we may accomplish in

this way what we performed previously by cutting off a portion of the battery, as already explained; and this is, in fact, the principle on which the dynamo currents are used in the quadruplex system.

Fig. 34 will show the manner in which these connections are made. In the present position of the transmitter in that figure the current flows to the post of the transmitter, thence to the tongue of that instrument, and after passing through the relays (not shown in this figure) to the line and rheostat. It will be seen that in this position of the transmitter there is also another route of 1,200 ohms resistance, but, as the present route via the transmitter offers practically no resistance, all the current will pass to the line by the latter route, where it divides equally between the two branches as described in Fig. 32.

When the transmitter is open, as in Fig. 35, the current necessarily flows through the 600 ohms at battery (which are inserted to

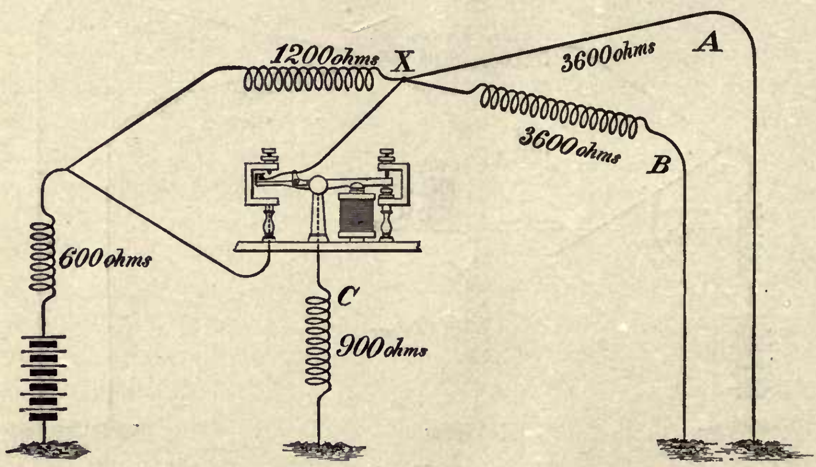


Fig. 35.

diminish the intensity of the dynamo currents, as mentioned in the description of the dynamo machines), and the 1,200 ohms added resistance, to the point *X*, where it divides as explained in Fig. 33, two parts of the entire current going to the ground via the transmitter and the 900 ohms resistance, (which is technically termed

the "leak,") and one part dividing between the line and the rheostat branches.

Since we know that by adding more resistance to a circuit having a stated electro-motive force we can reduce the strength of current on the circuit, the question may arise in the mind of the reader, why not simply arrange the connections so that when the transmitter is closed the added resistance should be out of the circuit, and when the transmitter is open the added resistance should be included in the circuit, thus dispensing with the third branch *C* or "leak"? The reason is, briefly, that the introduction of resistance for the reduction of the strength of current has been found to operate unsatisfactorily on quadruplex circuits; which is mainly owing to the fact, that so much resistance must be inserted in the circuit to cause the instruments affected by the increase and decrease of strength, to act quickly, that it has a detrimental effect upon the instruments worked by the changes of polarity.

The problem, therefore, to be solved was, how to arrange the connections for the dynamo machine currents, so that whether the transmitters were open or closed the resistance of the line should be the same, and the problem was finally solved by the ingenious addition of the leak in combination with the added resistance.

That this is so we may see by referring to Fig. 34 and following out the routes.

A current *coming from A*, in the position of the transmitter in this figure, would encounter, after passing the point *X*, 600 ohms, not counting the 1,200 ohms added resistance. In Fig. 35, after passing point *X* there is now a choice of two routes, namely, one via the 1,200 ohms added resistance and the 600 ohms at the machine (making 1,800 ohms), and the other via the transmitter and through the leak of 900 ohms. We know that the joint resistance of 1,800 and 900 ohms is 600; thus the total resistance from the point *X* to the various grounds at the home end remains the same in either position of the transmitter, while, as we have seen, the strength of current reaching the distant end *A* or *B* is materially altered at each change in the position of that instrument. Let the

reader bear in mind, therefore, that, notwithstanding the insertion and practical removal of these various resistances from the line, the actual total resistance of the quadruplex circuit is not changed. It is the insertion of the branch circuit, or leak to ground, that is the prime factor in obtaining the desired increase and decrease of strength.

In applying machine currents to the quadruplex, almost the same instruments as are used with a gravity battery will answer on short lines, where comparatively weak currents are used, but, where considerable strength of current is required, the spark produced at the contact points of the ordinary continuity preserving pole changer, at the moment of reversal of polarity, is sufficient to interfere with its satisfactory working.

For this reason a pole changer, such as is shown in Fig. 36, is used on long quadruplex circuits.

Its construction is very simple. The straight lever *L* is pivoted on the standards *S*, so that when either of the ends of the lever is depressed, it will come in contact with the upright post *Z* or *C* beneath it. The ends of the lever and the tops of these posts are furnished with platina contact points. The posts are insulated from the plate upon which they stand. The retractile spring is also insulated from the hook at the point *P* to prevent short circuiting. The line is connected to the lever via the standards *S*, and the two posts *Z* and *C* are connected, one to a positive series of dynamo machines and the other to a negative series. It may thus be seen that if the right hand end be depressed, making contact at *C*, contact will be broken at *Z* and a positive current will flow to the line.

With the left hand end depressed, contact will be made at *Z*, and the polarity will be reversed.

It will be noticed that, with this style of pole changer, contact is not made with one post until after the other has broken contact, and thus short circuiting of the battery is entirely obviated.

The figures which I have heretofore quoted, showing the amount of resistance placed in the "added resistance" as 1,200

ohms, and that in the "leak" as 900 ohms, give, as we have seen, a difference equal to 3 to 1, in the strength of current which reaches the distant station, in the different positions of the transmitter.

This margin is found sufficient on circuits of medium length, but on very long circuits better results are obtained when the margin

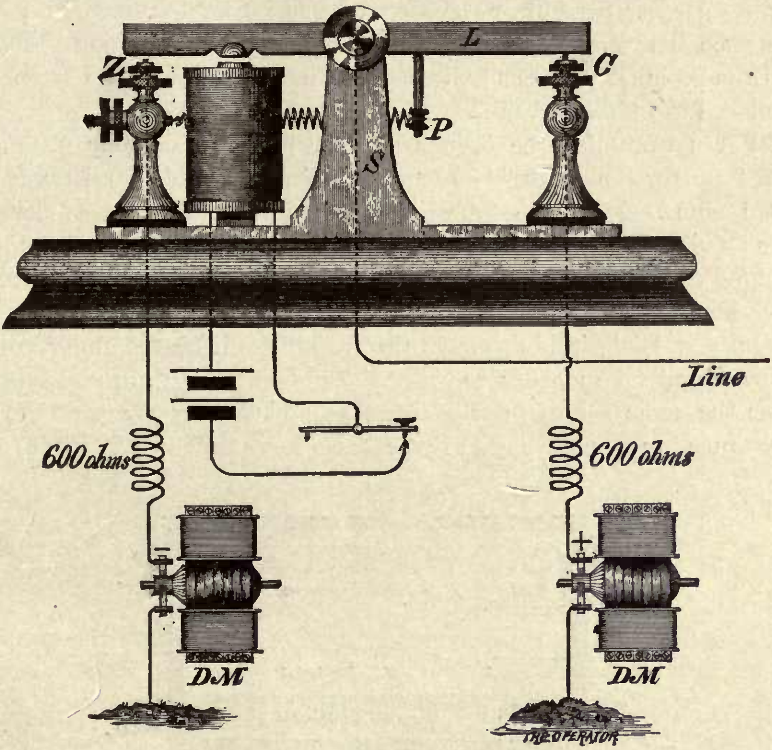


Fig. 36.

is made greater, for instance, 4 to 1. With a gravity battery the division of the electro-motive force necessary to obtain this margin is easily made by apportioning the "long" and "short" ends of the battery, respectively, the requisite number of cells to produce the desired result.

Thus in a battery of 300 cells, the "short end" would be appor-

tioned 75 cells to obtain this margin. But, as I have previously stated, it is not practicable to alter thus the electro-motive force furnished by the dynamo machines; therefore, when it is desired to increase the margin as above, namely, to make the ratio as 4 to 1, the resistance in the leak is made still lower (thus enabling it to carry a greater portion of the current away from the line), and at the same time the "added resistance" is increased. Of course these resistances must be so chosen that whether the transmitter is open or closed the total resistance of the line will be the same.

In actual practice the figures adopted for obtaining the ratio of 4 to 1 are, for the "leak," 800 ohms, and for the "added resistance," 1,800 ohms. It will be found that the joint resistance of 2,400 ohms (viz.: the 600 ohms at the machines and the 1,800 ohms "added resistance") and the resistance of the "leak," 800 ohms, is 600 ohms.

Since it is desirable to have the variable resistances under convenient control in order to work lines of any length or resistance upon the same set of instruments, the added resistance and leak resistance are usually placed in the same box, as shown in Fig 37.

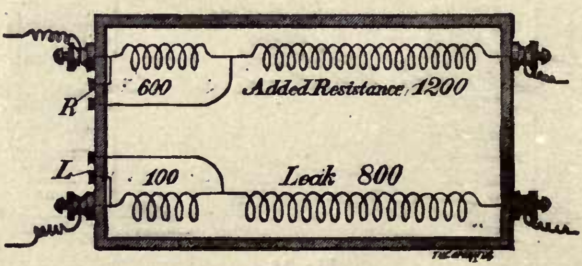


Fig. 37.

The leak consists of two resistance coils of 100 and 800 ohms, respectively, arranged in such a manner that by inserting a metallic plug at L the 100 ohm coil may be cut out. The added resistance coils measure 600 and 1,200 ohms, respectively, arranged so that the 600 ohm coil may be cut out by a plug inserted at R. Thus

the leak may be readily changed from 800 to 900 ohms, and the added resistance from 1,200 to 1,800 ohms.

When machine currents are used it is convenient to have some means of quickly opening the circuits between the machines and the home instruments, not only to facilitate any repairs or alterations that may require to be made, but also to cut out the instruments in case of short circuiting of the wires at any point. For this purpose each quadruplex set is furnished with a switch similar to the one shown in Fig. 38. The brass strips B and B'' are connected at their top ends directly with the dynamo machines, as may

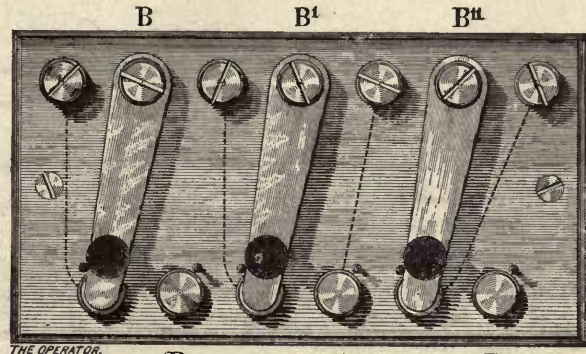


Fig. 38.

be seen in Fig. 40, while the strip B' is connected to the line. The lower ends of B and B'' are led to the posts of the pole changer. By moving B and B'' to the right they are placed on the dead points, D, D', and of course the machine currents are thus taken off the instruments. By placing the strip B' on the point G, the line is placed to the ground through a resistance equal to the resistance of 600 ohms at the machines. The dotted lines represent the connections between the buttons under the wood of the switch.

Fig. 39 is a diagram of the quadruplex arranged to be operated at station A by dynamo machine currents, and at B by the usual gravity battery currents. It will be seen that the latter's connec-

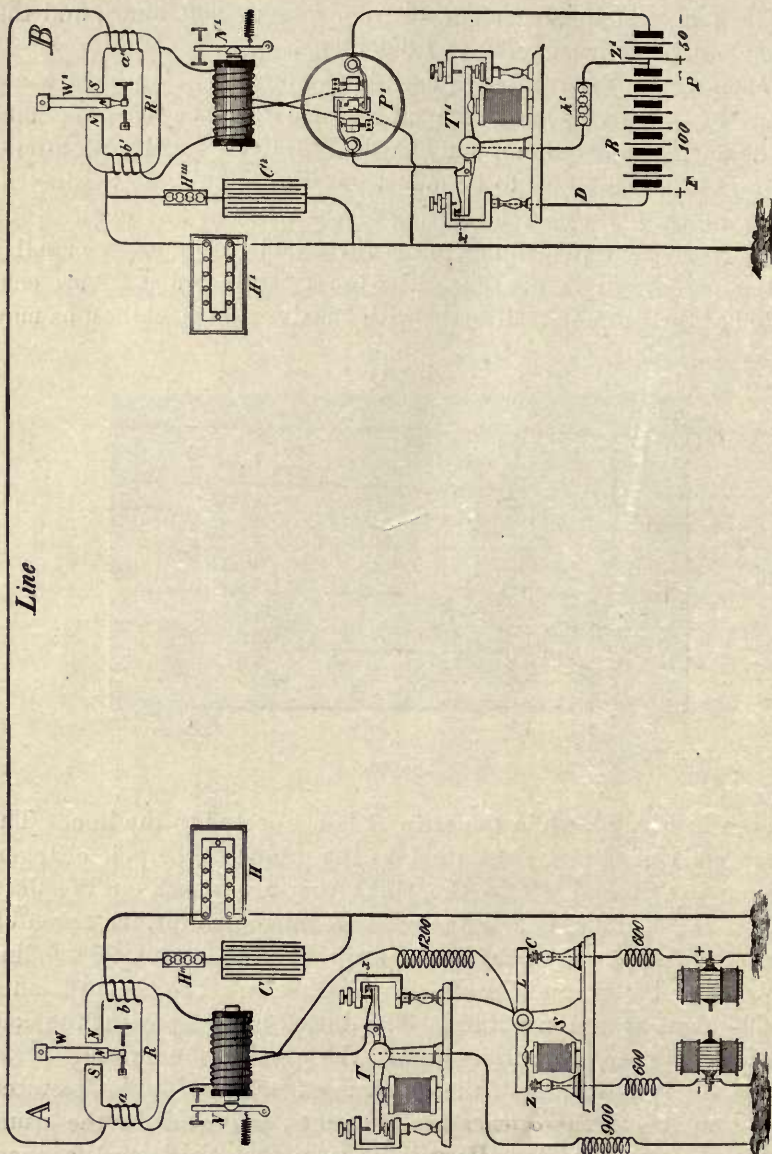


Fig. 39.—THEORETIC DIAGRAM OF DYNAMO QUADRUPLEX.

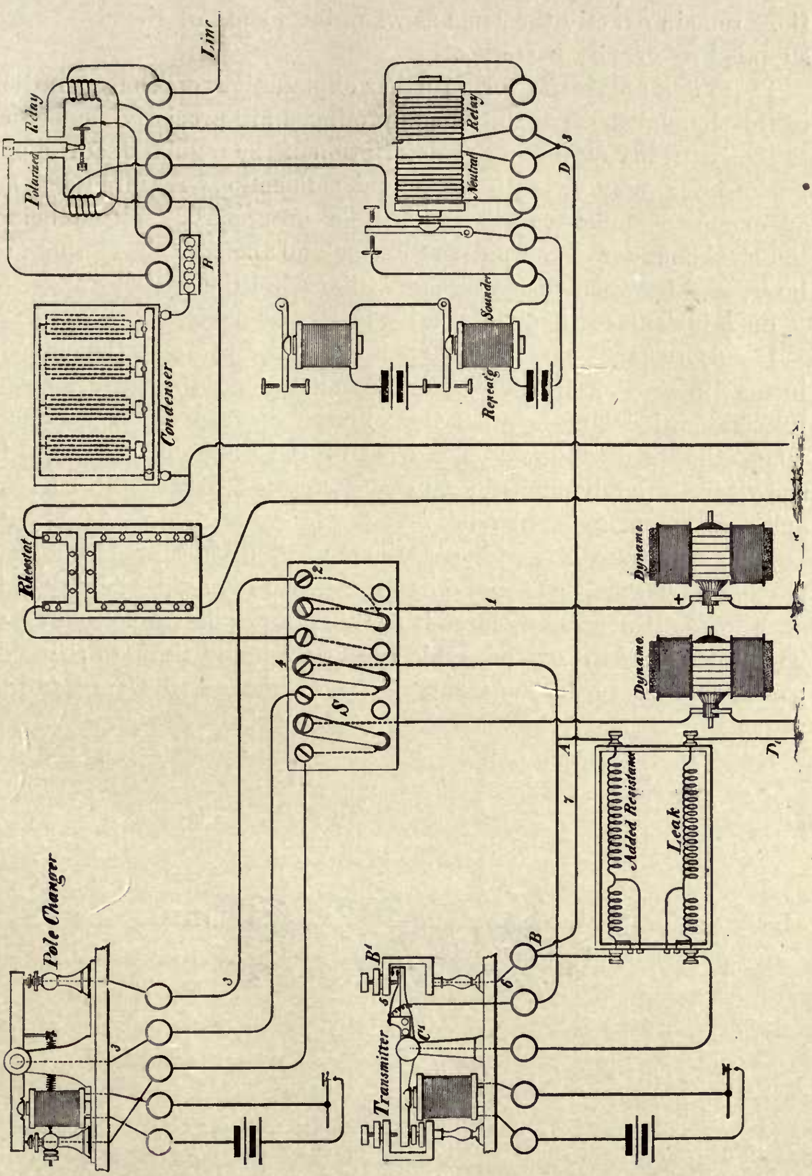


Fig. 40.—ACTUAL CONNECTIONS OF DYNAMO QUADRUPLEX.

tions remain exactly the same as when both ends of the circuit are supplied by gravity batteries.

There is no necessity for a further explanation of the operation of this arrangement, as the effects produced are precisely analogous to those already stated in the description of the regular quadruplex.

In Fig. 40 may be seen the actual connections required by the arrangement under consideration, the only parts omitted being the local sounder of the polarized relay and the resistances that are interposed between the dynamo machines and the switch *S*.

Each instrument is plainly indicated by its name.

It only remains, therefore, to point out the route of the current in the different positions of the transmitter, and these are located by consecutive figures and letters in the diagram. For instance, when the transmitter is closed, as in the diagram, the route is shown from the dynamos by figures 1 up to 8, where the current splits, as heretofore explained.

When the transmitter is open, the current divides at *A*, and that portion which proceeds to the line passes through the added resistance to *B*, thence to *D*, where it again splits, as in the former case. That portion of the current which seeks a ground through the leak passes from *A* to the tongue of the lever, thence to *C'* and to the ground.

CHAPTER IX.

The Practical Working of the Quadruplex.

BY WM. MAVER, JR.

After first-class instruments, perfect connections, and well kept batteries, nothing conduces so much to the successful working of the quadruplex as intelligent handling.

By intelligent handling, I mean that the persons in charge of a quadruplex set or sets should have a thorough theoretical and practical knowledge of the entire system. The theory may be mastered by study, but the practical knowledge can, as a rule, only be gained by experience.

It is not, however, always practicable to have an experienced person in charge of a system, for it frequently happens that a quadruplex circuit is installed in an office and placed under the care of a manager or chief operator who may never have seen a quadruplex set before.

An enterprising manager, in such a case, will, of course, at once endeavor to post himself in all the details of the system, but these are more numerous than some people suppose, and while the manager is acquiring his knowledge the best results cannot be expected from that particular quadruplex system.

In the hope that my experience may be of service to this class in the management of their quadruplex, as well as to others who may wish information on this subject, I propose to jot down as many of the causes of trouble, and the symptoms occasioned by certain kinds of trouble, as I can recall, together with any hints as to the manner of obtaining the best results from the system, that may occur to me.

The following are some of the technical terms and expressions used in speaking of the quadruplex and its connections:

The "tap" or "tap wire" is that wire which taps the battery and

is led to the bar of the transmitter. It may be seen at point *Z* in Fig. 28. The "short end" of the battery is that portion between the ground and *Z* in the same figure. The short end is generally to the line when the transmitter is open. The "long end" of the battery refers to the portion between the points *P* and *F*, also in the same figure. This is referred to chiefly when there is apparent trouble in that portion of the battery, as explained hereafter. To "reverse" means to open and close the pole changer, which instrument, as is well known, reverses the battery at each motion.

The "ground coil" is that resistance which is placed between the three point switch *B* in Fig. 30, and the ground, to compensate for the internal resistance of the entire battery. It is sometimes called the "spark coil."

The "polar relay" is the No. 1 relay. The "neutral relay" is the No. 2 relay.

To "dot" or "write on both sides" is to write on the pole changer and transmitter simultaneously.

Care should be taken that the compensating battery resistances, such as that between the tap of the battery and the bar of the transmitter, are correct.

It may be assumed that two and one-half ohms per cell is the average internal resistance of a battery cell.

On circuits of, say 100 miles, it is common to divide the battery into two equal portions, namely, (supposing that there are 100 cells in the battery,) of fifty cells each.

Thus when the transmitter is open fifty cells are placed to the line, and when it is closed, 100 cells. This is called giving a margin of two to one.

On longer circuits the margin is made wider, until on some circuits, such for example as that between Bangor, Me., and New York, it is four to one, that is to say, (supposing that there are in all 400 cells of battery,) there would be 100 cells to the line when the transmitter is open, and 400 when closed.

This increase of the margin is rendered necessary by the fact that on long lines there is considerable retardation and prolongation

of a current, and it is thus essential that the difference of potential between the entire battery and the "short end" of it should be greater, so that the variations in the amount of current reaching the distant neutral relay may be more marked.

The method of balancing a quadruplex has already been explained in the foregoing chapters, but it is a subject which I am sure will bear amplification.

As already stated, the distant station, which for the sake of brevity I shall frequently hereafter call *B*, is first requested to "ground." Having done so, he should avail himself of the opportunity to see that the number of ohms resistance in his "ground coil" is correct. The ground coil is that resistance which is interposed between the line and the ground, when one "grounds." As previously mentioned, the ground coil is put in to compensate for the "internal" resistance of your battery. It very often happens that an inexperienced "balancer" will unwittingly alter this resistance, to the serious detriment of your balance. For instance, if the internal resistance of a battery is 600 ohms, and by inadvertence 1,200 has been inserted, it will divert an unequal portion of your battery current to the line, and thus render your balance unsteady. Of course it is equally necessary that you should examine your own ground coil.

When *B* has grounded, you also ground.

The next thing to be done is to place the armature of your polar or No. 1 relay in the "center," that is, so to adjust it that it will remain on whichever side it is placed. You then "cut in" your battery and change the resistance in your rheostat until the lever again remains where it is placed.

Sometimes it happens that, owing to heavy inductive effects on the wire, it is impossible to find this center, the armature keeping up a constant clatter. In this case you must use your judgment and adjust the armature in that position where the attraction to either pole of the relay is about even. You then, as before, place your battery to the line. If the wire is much out of balance, the armature of the polar relay will now be strongly attracted to one side, in that case, alter the rheostat resistance again. As you ap-

proach the balance, the inductive effects of the line will again begin to be felt, and again your judgment must be exercised as to when you have a nearly perfect balance. When this is obtained, request the distant station to "cut in" his battery; when he does so you will very likely find that the inductive effects have disappeared, having now been overcome by the distant station's battery.

On wires not exceeding from 70 to 100 miles the static discharge from the line is scarcely sufficient to interfere with the working of Morse circuits, therefore, on such wires condensers are unnecessary.

A few words more, here, explanatory of the static discharge or return current, may be of use to the beginner.

To illustrate, let us suppose that we have a pipe between any two points, somewhat remote, and let us further suppose that we have at one end of this pipe an engine pumping water through it. Also let us suppose that we have at each end of the pipe a wheel, which will be revolved in a certain direction accordingly as the water flows. Now if we suddenly stop the pumping engine, leaving at the same moment both ends of the pipe open, it is quite evident that the water in the pipe will empty itself at both ends, and the water at the end where we had supposed the engine to be will run out in an opposite direction to that in which it had been flowing into the pipe, and if there is enough water so left in the pipe, as there probably will be if the pipe is sufficiently long, this returning water will reverse the direction of the wheel.

If we could imagine that the sides of this pipe were of a spongy nature, it would be easy to believe that the capacity of the pipe for holding water would be increased, and, consequently, the greater would be the outflow of the return current when we should suddenly stop the engine, and the greater would be the effect of this outflow upon the wheel.

Now the foregoing action of water in a pipe is partly analogous to the action that takes place in a telegraph wire. The battery supplies the electric current on the wire. The action of induction, previously explained under the heading of condensers, gives to the wire a greater capacity for retaining electricity. The pole changer

momentarily cuts off this supply of electricity. The electricity left in the wire at that moment seeks to return to the earth, and in doing so temporarily charges the relay, giving a short false signal.

The condenser obviates this trouble in the manner already explained. It should be stated that the coils in the rheostat which form the artificial wire have a very small capacity for retaining electricity, and hence, although they offer, when properly adjusted, as much resistance to the electric current as the main line, do not, at the moment when the battery is cut off, send back anything like so large a return current.

The condenser being placed in the artificial line, as shown in the diagrams, when rightly adjusted gives that wire an artificial capacity equal to that of the main line, and as the condenser discharges at the same moment as the main line, but goes around the core in an opposite direction to the line discharge, the home relay is not affected.

After having balanced the quadruplex, it now remains to adjust the condenser so that it shall give a discharge equal to that from the line. This requires a greater degree of skill than simply to balance a quadruplex and almost every expert has his own way of proceeding. I have found that I could always eliminate the static effects by simply closing the No. 2 key, (so that the full battery will be to the line,) and dotting on the pole changer, in the meantime adjusting the condenser, by taking out or putting in plugs, until the motion of the polar relay in response to my pole changer was reduced to a sort of a light double click.

So long as the polar relay responds clearly to each motion of your pole changer, the static balance may be considered imperfect.

Another method for adjusting the condenser is, after balancing, to give the adjusting screw of the polar relay a bias to one side or the other until a well defined click is heard, then to insert or remove plugs in the condenser (at the same time bringing back the armature of the polar relay to its former position) until this click is eliminated.

I consider that this method has a defect, especially in the hands of beginners, as it alters the "center" of the polar relay armature

and may thus interfere with the satisfactory working of the polar side.

Another method, and a very good one I think, is, after balancing, to request B to put his battery on, and to so place his key that your polar relay armature rests on the local contact point. See that your own full battery is also to the line. Now dot on your pole changer and adjust your condenser until it has no effect whatever on your polar relay's armature. If the static discharge has no effect on your polar relay under the above circumstances, it will not be likely to effect it under any other circumstances.

The reason I advise noticing that your full battery is to the line, when you are adjusting for "static," is, that the static discharge varies with the amount of battery to the line. The greater the amount of battery to the line the greater will be the return discharge.

After this has been done and the distant station has also balanced, the following test should be made to ascertain whether the adjustments are correct:

Ask B to dot on his No. 1 side and to write on the No. 2 side. Now listen to see that B's writing on No. 2 side is coming all right, at the same time open and close your own pole changer and transmitter. If you get his writing clearly under these circumstances, which of course is equivalent to having all sides working at once, your balance is correct.

The distant station should then go through the same performance.

If it should transpire that while B is writing on both sides you do not get him clearly on No. 2 side, after you have carefully adjusted, request him to write on No. 2 side only. If, while he is so writing, his pole changer should be open, and you get him O. K., next ask him to close his pole changer and to continue writing on No. 2 side. If you also get him O. K. with pole changer closed, it would appear that the trouble is in his pole changer's points, and in that case an examination of them will probably reveal that the trouble was caused by dirty points, or uneven contacts.

When your No. 2 side is broken up by the movements of B's pole

changer, it is technically said that his "reversals" break up or confuse No. 2 side.

A small file, adapted to go under the contact points of the pole changer and transmitter, is a tool every manager of a quadruplex set should possess.

If, after B has cleaned his points, the trouble be not removed, try your balance again carefully. This is especially necessary in bad weather.

If you get B's writing "light" on either side, ask him to clean his points on both sides. Should he complain that you come "light," likewise clean your points "all around." When the contacts become oxidized it is well known that this increases the resistance at the points of contact, and consequently the strength of current is reduced.

If, while B is dotting on the pole changer, you are unable to read him on No. 2 side, again get him to write on No. 2 side only, and request him to give you one pole at a time. This he does by first closing and then opening his pole changer, as you direct. If you find that when he closes his pole changer, for instance, you do not get him at all on No. 2 side, while you do get him while his pole changer is open, it indicates that one of the tongues of his pole changer is not making connection; call his attention to that fact.

If while B is dotting on No. 2 side you cannot get him readably on No. 1 side, likewise ask him to give you his full battery and his short end alternately. This he does by first closing his transmitter (giving you all of his battery). If now you do not get him on polar side, next ask him to give you his short end, which he does by opening his transmitter; if now you get him, it indicates that there is trouble between the "tap" of his battery and the post of his transmitter, probably a bad or broken connection in battery; or it may be that the tongue of his transmitter is not making proper connection with the post of transmitter.

Should the trouble be that you do not get him when his transmitter is open, while you do when it is closed, the trouble would appear to be that there is either a bad connection between where

his battery is tapped and the bar of his transmitter, or that perhaps the tongue of the transmitter is not making proper contact with the bar of the transmitter.

By reference to the diagrams of the quadruplex, Fig. 28, it will be seen to what I allude.

If it happens when all sides are working that you do not get B well on No. 2 side, notice carefully whether you do get him all right on that side when your No. 1 side is quiet. If so, the trouble, most likely, is caused by an imperfect static balance at your end. If you find you do not get B well on No. 1 side when your transmitter is closed, but that you do when it is open, this trouble, too, is probably occasioned by bad static balance.

If you find that your condenser seems to have no effect on the static discharge, in the way of removing it, examine the connections of condenser; it may be that they have become detached. It is as bad to have too many of the condenser plates in action, as too few. Therefore such an occurrence should be avoided.

It occasionally happens that when one wire becomes crossed with another, one of the wires is cleared by opening the other at both ends.

If the wire so cleared should be a quadruplex or duplex wire, the effect on the static discharge will be at once noticeable, namely, it will be much increased. It is in some cases necessary to add another condenser to offset this abnormal discharge; an additional amount of resistance placed between the condensers and the artificial wire may also be thus rendered necessary, as the static discharge in this case is somewhat more gradual than ordinarily.

When a wire has not been balanced since the previous day, and if in the meantime the weather has considerably changed, or if there has been a decided change in the weather at any time, it may occur that you will not hear B calling or answering your calls, the wire being so much out of balance. In this case it is a good plan to call B a few times, and then suddenly ground your end. If B is there, and answers you, you will be sure to hear him now. If so, cut in again, ask him to ground, and proceed with your balance as usual.

When there has been a change in the weather from dry to wet, it will probably be necessary to lower, very considerably, the tension of the spring of No 2 relay, before you will be able to get B. This is because the margin of his current reaching you has fallen in proportion to the state of the weather, as well as the condition of the wire insulation.

On the contrary, if the weather changes from wet to dry, it will be found necessary to increase the tension of the No. 2 relay, the margin from B having increased.

After a balance has been taken on the quadruplex, it is, generally speaking, best not to alter the adjustment of the polar relay under any circumstances. I am aware that some quadruplex experts favor giving the armature of this instrument a bias to the local contact point, but I do not think the theory of the quadruplex will justify this action. It should be considered that the object of placing the armature in the "center," before balancing, is to make certain that the amount of current flowing through each coil from the home battery shall be equal; and that the quadruplex is actually worked by the production of inequalities of the currents flowing through these coils, and thus, that any bias to one side, which may be given to the lever, is equivalent to sending more current through that side from the home battery. Furthermore, the fact of the lever being exactly in the center is relied upon to keep it perfectly still when the distant battery is momentarily cut off during the changes of polarity at the distant station, for at that instant, as we know, the induced magnetism of the polar relay comes into play and retains the lever at whichever side it may happen to be at that moment. Consequently, if the lever is biased, it is possible that should the lever happen to be on the unbiased side it might tend to move to the other side and thus make a "click."

It is true that if but one side of the quadruplex is working, a change in the balance may be tided over by simply changing the adjustment of the levers, but this is only a makeshift at best. Should writing from B come light on the polar side, the true remedy does not consist in biasing the armature. First ascertain that the

trouble is not in a weak local, dirty contact points, bad adjustment of sounders, or in your balance; after that, request the distant station to diminish the tension of the spring on his pole changer. If none of these resorts obviates the trouble, and the batteries and wire are all right, it might be well to try what result would ensue from a change of the sending operator. It has often been noticed that some operators do not seem to have the correct method of sending signals through on duplex or quadruplex circuits.

Where a repeating sounder is used on the No. 2 side, trouble is sometimes caused by its contact points sticking, or becoming loose; they should be looked after.

In balancing you may sometimes find it impossible to get "a balance," and that no amount of changing of the rheostat resistance produces any effect on the relay. This, however, does not occur very frequently. It may be owing to several causes. For instance, the polar relay may have become defective; burned out, as it is called, by an unusually strong current, such as lightning, etc., or the rheostat may have failed, some of the coils thereof having broken, perhaps; or the trouble may be in the condenser. This would be the case if a ground plate should touch a line plate. This may be tested for by temporarily detaching the wire from the condenser.

The relay may be tested by taking out all the wires from its thumb screws but the battery wire, and by feeling with wet fingers, or a piece of wire, to ascertain whether the current comes through to any of the other thumb screws than the one it naturally should come to. The permanent magnet should also be tested to ensure that it is not crossed, by way of the core of the electro-magnet of the relay, with either of the coils. It is understood, of course, that if the fingers are used for this test, the other hand must be touching a ground wire, or if a wire be used, one end of it must be to ground. The wire is the best, as it will show, by a spark, a lower current than the fingers would detect.

The neutral relay may also be affected and tested in the same way.

If the current should be found in other than the thumb screw

which is the terminus of the coil attached to the battery as above, it shows the relay to be defective, probably the coils are crossed with each other.

Another source of trouble is the crossing of a portion of one coil with another portion of itself, which would make the resistance in the crossed coil of the relay much lower than the uncrossed one, as the wire between the crossed portions of the crossed coil would be virtually cut out.

The effect of such an occurrence is this: Suppose that it is the line coil which is crossed with itself. In consequence of this cross there is less aggregate current flowing in that coil around the relay core than through the rheostat coil. It will thus follow that the strength of current flowing through the line coil must be increased in order to enable us to balance the relay lever. To produce this result we shall find that we will have to largely increase the resistance in the rheostat to divert a greater portion of the current to the line; but, of course, a quadruplex will not work well on a balance obtained in this way.

When an abnormal balance, such as the above, is obtained, it is a good plan to ask the distant station how many ohms resistance he obtains a balance with. If his balance is normal you may suspect either of your relays, and examine them, although it does not follow always that the trouble is there.

It is presumed that every person in charge of a circuit knows the normal resistance of the wire under his charge. Therefore, if the balance should give about twice the usual resistance, it is likely that the ground coil at the distant end has become detached, and in consequence you are not only balancing against the line but also his rheostat, through which you are getting your "ground." This trouble is comparatively easy of detection.

When it happens that B does not get any battery from you on a certain quadruplex, and has informed you to that effect, via another wire perhaps, it is best, first to ascertain whether your battery reaches the switch, testing for it in both positions of your pole changer and transmitter. If it does not, then the fault is, of

course, located between the switch and the quadruplex battery. Next test for the battery at the screw-post of the polar relay from which the wire runs to the switch; next at the screw-post of the same instrument where the line wire enters the relay; next at the screw-post of the No. 2 relay whence the line wire makes its exit, and afterwards at the screw-post at which the line wire enters that instrument. Suppose that at this latter post you feel battery, but do not at the exit screw-post, in such an event it locates the fault between these two points. It is probably a broken wire under the base board of the instrument, one of the fine wires. But, wherever the trouble may be, it is most quickly and certainly found by this point-to-point test. A correct diagram of the connections is, therefore, very essential to enable those who cannot carry the connections in mind to follow out the route of the wires.

It should be borne in mind that if the trouble is occasioned by the current having found a short route to the ground, as sometimes happens, it will be almost impossible to locate the trouble with the fingers, as the metallic route to the ground offers so little resistance to the current, in comparison with that offered by the body, that not enough current will pass by the body to make itself felt.

When "deep seated" trouble has overtaken a quadruplex circuit, and it is uncertain at which end of the wire the trouble is (the wire having, of course, been changed for one known to be reliable, so that the fault cannot be laid to it), and each station claiming that the fault or "bug" (as a fault on multiplex systems is now generally technically termed), is at the other end, the best plan, by all odds, is to ask the distant station to test your quadruplex set against another set in his office, if he has more than one set. If not, test your set against a set known to be free from trouble in some other station. Should the same trouble still appear in your set, that, of course, proves conclusively that the trouble is in your set. If your set now works O. K., however, it as certainly shows that the seat of the fault is in the distant quadruplex, and the manager thereof should be informed of the result of said test; whereupon, it is to be supposed that he will set about with renewed

vigor to locate the fault, and generally with better success. You need not be surprised, however, after the trouble has disappeared, should the distant station calmly ask you, notwithstanding the circumstances, "What did you find?" The importance of keeping all the locals connected with a quadruplex set in first-class condition, and all the local contact points well cleaned, cannot be mentioned too often. The locals should not be allowed to run down until they actually fail, before renewal, nor should the local contact points be permitted to remain unfiled until they actually stick.

It has frequently happened that quadruplex sets have been rendered virtually useless for days at a time, the trouble being attributed to main line or main battery faults, instead of which it has been an unheeded weak local or faulty local contact point.

It would be impossible to enumerate all the different sources of trouble which are likely to arise on a quadruplex system. Those that I have alluded to are among the most frequent.

It would undoubtedly add much to the successful handling of the quadruplex if every one connected with it would frankly state the cause of trouble, when he has found it, to the operator or person in charge at the other end. The latter has seen the symptoms occasioned by the trouble. If he were at once notified as to the exact nature of the fault, he would be able at once to direct the distant station to the seat of trouble, when next the same symptoms should manifest themselves, and thus time would be saved. Instead of so doing, however, it has become almost a rule for every manager to hide any trouble happening in his own set, and merely to say that probably a loose wire "shook out," or something equally vague. This pernicious custom is probably due to the fact that some superintendents require so many explanations as to the reason why such and such trouble was not obviated, or not discovered sooner, that a manager rarely allows a fault to be definitely located in his office more than once. It is thus, perhaps, an open question whether it is really to the benefit of the service that managers, who, as a rule, are not apt to willfully allow trouble to occur, or to sit idly by when it has occurred, should be held so strictly to task.

TELEGRAPH REPEATERS.

BY WM. MAVER, JR.

After Columbus had shown the wise men of Spain how an egg could be made to stand on end, they doubtless conceded that it was a very simple feat, although they had previously spent some time and thought in the attempt to solve it; and it is likely that had any one ventured on a second explanation of the mystery, the wise men would have considered it quite unnecessary.

In like manner it is possible that to those who, by study or explanation, have familiarized themselves with the principle and operation of the standard repeaters, an article on that subject at this late date may appear superfluous; but to such as have not been shown how the egg may be made to stand on end, so to speak, the subject is as obtuse as it ever was.

It is very questionable whether, on an average, one out of ten operators throughout the country is familiar with the principle or mode of operation of any of the repeaters now in use. Indeed, the writer has been told by several of his friends that they have found the action of repeaters as difficult to comprehend as that of the quadruplex.

This is, no doubt, an exaggerated statement, but it is nevertheless true that to many the manner in which the repeater performs its functions is a mystery.

This condition of affairs is probably due in many cases to a total lack of interest in the matter. Again, it may be owing to a habit which some inventors or draughtsmen have of displaying their diagrams to the very worst advantage, with regard to clearness, so that to a novice it becomes an almost insurmountable task to follow out the labyrinth of lines, crossed in some places so carelessly that it is difficult to determine whether a joint is not meant; and in

other places so poorly jointed that it becomes a question whether the lines are not meant to cross each other *there.* In other diagrams the student traces a wire until it is brought up to the screw post of a certain instrument, and there it stops short. He sees that several other wires lead out of that instrument by other screw posts, but which of those is the one he wishes to trace is a discouraging conundrum.

These, at least, are some of the difficulties which met the writer in his search after knowledge on this and like subjects, and, consequently, in the following descriptions he will strive to avoid falling into similar errors.

In the days of stage coaching, as we are all aware, a pair, or maybe two pairs, of horses would be detailed to draw the coach to a certain station, having reached which point they were relieved by a fresh set of horses termed a relay. The stage was then drawn by these horses to the next relay station, when another change of horses would be made, and so on.

The obvious reason for these changes or relays was that the horses had become fatigued, and although they might have gone farther, the work would not have been done so quickly or so well as by the fresh set of horses.

Now, what the relay of horses did for the stage coach, repeaters practically do for the telegraph message. They take it off the hands of a tired wire, if such an expression may be used, and pass it on with fresh vigor to another wire.

It is a question whether the name "repeater," as applied to the repeater of to-day, is not a misnomer, or at least somewhat inappropriate. The instrument which we know as a "relay" is, perhaps, more correctly a repeater. It repeats to the sounder what is passing on the main line. The instruments composing an automatic repeater do relay the message from one wire to another, which is exactly what the relay did when its present name was given to it by Morse, as will be shown later.

Repeaters are rendered necessary on telegraph wires, because it is impossible to insulate a wire so perfectly that a portion of the

electricity on the wire will not escape at each point of insulation. Hence a certain amount of electricity passes to the ground at every pole along a line, and consequently the longer a line may be, the more electricity will escape to the earth in this manner, so that on long lines (or even on short lines in wet weather, for then each insulator becomes comparatively a better conductor, and so permits more current to escape,) the current that reaches the distant end becomes quite feeble. But, even if the question of imperfect insulation were set aside, the operation of Ohm's well-known law of electricity, viz., that the strength of current on a line is equal to the electro-motive force divided by the resistance of the wire, would confine the successful working of a circuit within certain limits. Therefore it is found advantageous on circuits over a certain length to insert midway, or at stated intervals, sets of repeaters, with fresh batteries, etc. The intervals at which repeaters are placed of course depend to a great extent on the conducting capacity of the wire used.

Professor Morse at first had an idea that the best effects could be obtained from an electro-magnet (designed for telegraphic purposes) by winding it with wire of the same size and material as that used on the line. The consequences were that the instruments were not only very unwieldy, but very poor magnets. It is easy to imagine that such was the case when it is stated that the first pair of magnets made for Professor Morse weighed, including attachments, three hundred pounds each. Mr. Charles T. Smith, now employed by the Western Union Telegraph Company in New York city, who was connected with the Morse telegraph system in its earliest days, and to whom I am partly indebted for this interesting information, subsequently made two electro-magnets coiled with a somewhat smaller gauge of wire than those just mentioned. The coils of Mr. Smith's magnets were first covered with gum shellac, and afterwards with a coating of thick glue. They only weighed seventy-five pounds each.

Professor Morse very early in his experiments discovered that he could not generate sufficient magnetism to operate his electro-magnets at a greater distance than from fifteen to twenty miles, the

cause of which, as we know now, and as Morse afterward learned, was that his electro-magnets were wound with such coarse wire that there were comparatively few convolutions around the core of the magnet, and as the strength of an electro-magnet increases with the number of convolutions of wire around the core as well as with the strength of current flowing through the coils, the resultant magnetism in the professor's first instruments was very feeble. The idea struck him, however, that while he could not satisfactorily operate his magnet on a line of any great length, yet he might cause a magnet operated at a limited distance to transmit into another wire of the same length, and then cause that second wire to repeat into a third wire, and so, as he thought and said, in this way encircle the globe with a wire.

Fig. 41 shows the manner in which the professor proposed to prolong his circuit. It is seen that line A relays into line B by means of the armature of R', and B into C by the aid of R'', and so on. But by this arrangement it will be observed that there is no way of sending messages back from D to A. To overcome this, Mr. Morse used another wire, as seen in Fig. 42, giving R' in that figure control of line B, etc. The electro-magnets which performed that service Mr. Morse properly termed relays, and that name all line electro-magnets have since retained, so that when automatic relaying instruments were invented, the word repeater was probably applied to them as a distinguishing name. A working model of this method was publicly shown in the University of New York, but it never went into practical operation. Mr. Morse, however, adapted this invention to the work of operating the secondary or local circuit, and the manner of operating the relays was maintained a profound secret for a long time, the magnet and its connections being enclosed in a locked box.

The Button Repeater.

In 1846, the Woods button repeater was introduced; but in the meantime, by the use of improved electro-magnets, the distance at which relays could be practically worked had much increased.

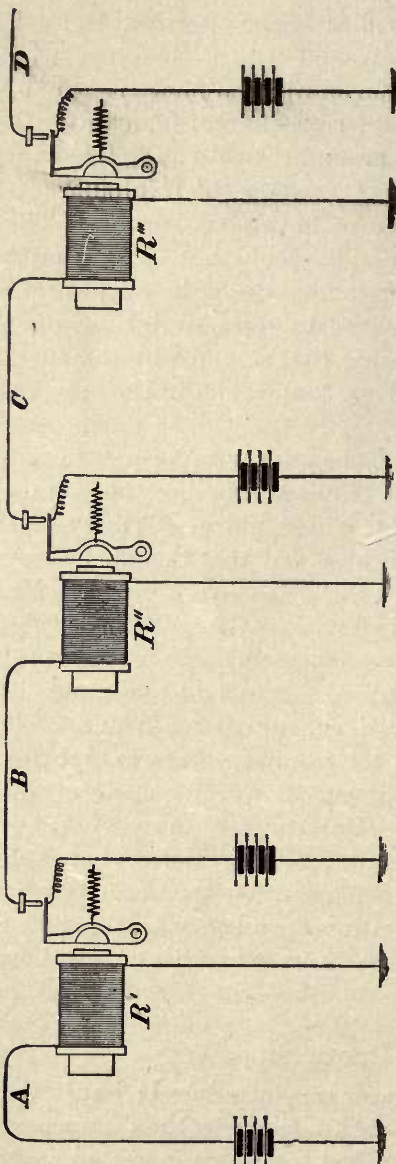


Fig. 41.—MORSE'S METHOD OF RELAYING.

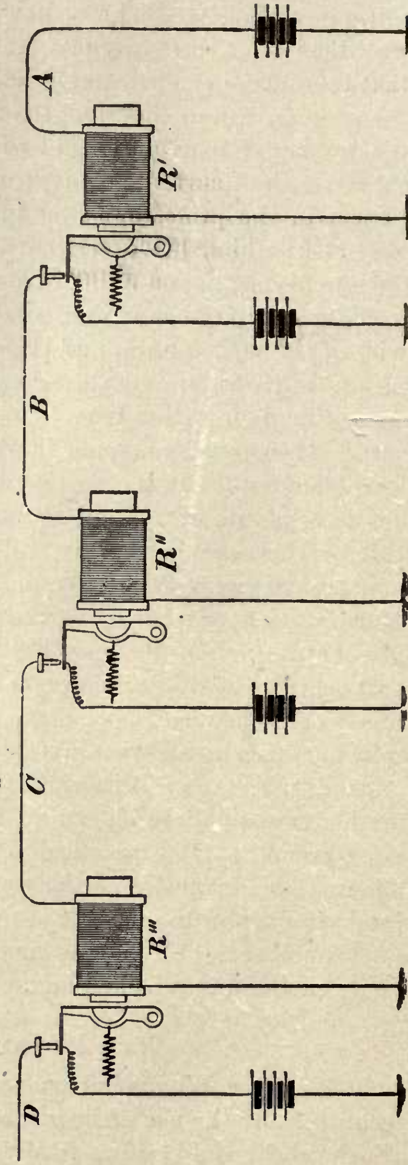


Fig. 42.—MORSE'S METHOD OF RELAYING.

Fig. 43 is a diagram of an improved form of button repeater now in use.

Before describing its action let us first investigate the necessity for such an instrument, and for this purpose the reader will please consider that for the present the dotted lines *D D D′ D′*, and the button switch *B R* are out of the circuit.

By examining the diagram it will be seen that line No. 1 runs through relay *R′* and is led through the armature of the repeating sounder *R S′* to the battery *B′* and ground; and that line No. 2 goes through *R″* and through the armature of *R S* to its battery *B* and ground. By this arrangement *R′*, having control of *R S* by means of the local circuit, should, it would seem, be able to open and close No. 2 circuit at the point x at pleasure, and in like manner *R″*, having control of *R S′*, should be able to close and open No. 1 circuit. But it is not so, for let us suppose that an operator on No. 1 circuit opens his key; this allows the armature of *R′* to fall back, which in turn opens *R S*, and its armature, being drawn up by the retractile spring, opens the No. 2 circuit at x. This action opens relay *R″*, which in turn opens *R S′*, and the latter breaks the circuit of No. 2 line. This is all right so far, apparently, for we have both circuits open, but the operator on No. 1 line now wishes to close his circuit, and consequently closes his key, but that does not close his circuit, as it is still open at *R S′*, and thus No. 1 circuit remains open, precisely as if an operator at a receiving station had his key open, and in that case No. 2 circuit is also kept open; hence a deadlock must ensue. This was probably the reason why Morse suggested the use of two wires for his system of relaying. At all events it is a sufficient reason.

Now, to describe in what manner the button repeater overcomes this trouble, let us consider that the dotted lines *D D D′ D′* and the button switch *B R* are now in the circuit. We will assume that No. 2 line wishes to send into No. 1.

For this purpose the operator attending the button repeater at the repeating station *A* turns the button to the left as shown in the figure, so that a strip of metal indicated by the short black lines on

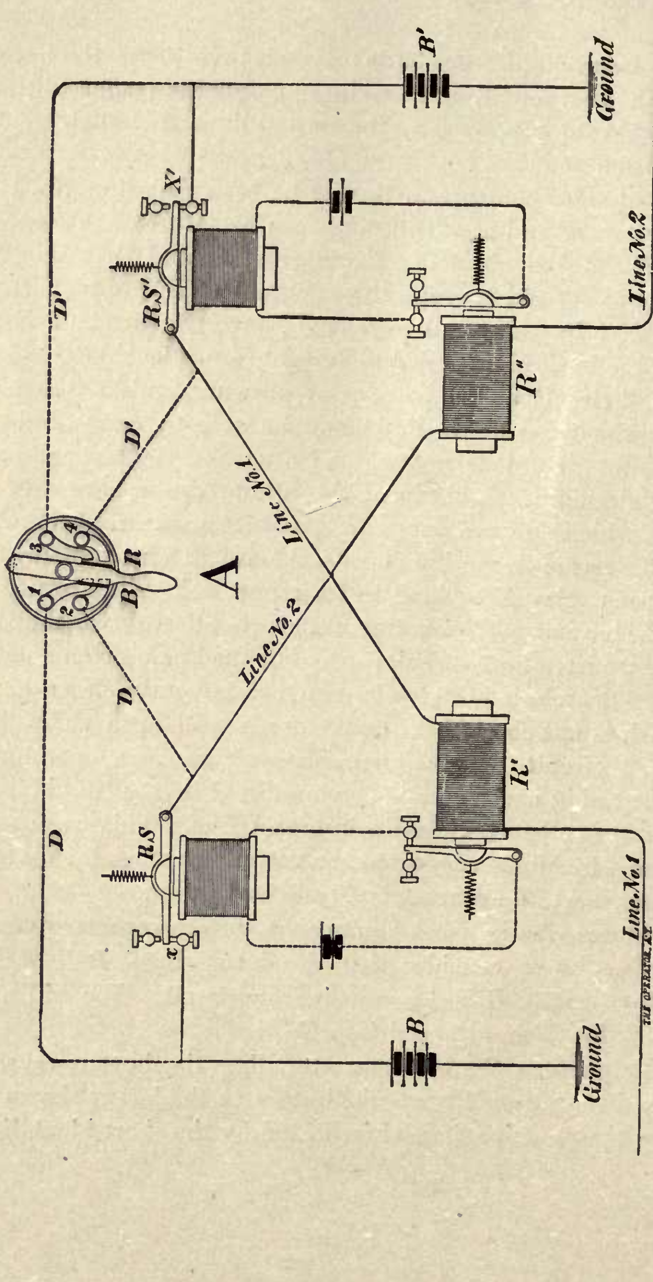


Fig. 43.—DIAGRAM OF BUTTON REPEATER.

the handle of the button switch joins the metal points 1 and 2 together. This gives line No. 2 two routes to battery *B* and ground, one *via* the dotted lines *D D*, and the other *via* the armature of *R S*. Again assume that No. 2 opens his key; the armature of R'' falls back and opens the local circuit of $R\ S'$, which breaks line No. 1 at x', and this again opens R', which of course opens *R S* and breaks line No. 2 at x, but the route *via D D* remains intact, so that No. 2 can close his own circuit when next he closes his key, which in turn closes R'', which closes the local circuit of $R\ S'$, and this again closes No. 1 circuit. Thus, as long as the button switch is held in that position, No. 2 can repeat into No. 1. Should No. 1 wish to break No. 2, the attending operator at *A* turns the button so that it will cover contact points 3 and 4, which gives No. 1 the same control over No. 2 as the latter previously had over the former.

One advantage that this form of button repeater has over some others is, that when the handle is directly in the center, each line may be worked from station *A* as independent circuits.

Button repeaters are also useful when it is necessary to send copies of the same press reports over two different circuits from a central circuit, *A*, for instance, in the diagram. When used for this purpose a key is inserted in either No. 1 or No. 2 circuit at *A*, and thus the operator at *A*, by moving the handle to the proper side, can transmit into both circuits.

Automatic Repeaters.

In the description of the button repeater, Fig. 43, it was shown that it was necessary to keep the circuit of the sending office intact at the repeating station, at the same time that the said sending office was enabled to repeat into another circuit by having control of a repeating sounder, through the armature of which the wire of the circuit to be repeated into was led. We saw in the explanation of the button repeater that this object was accomplished by means of the metal strip on the handle of the button switch, and the dotted-line circuit, which insured a continuous circuit to the sending office.

This plan for repeating, however, while quite successful, had a bad feature, inasmuch as it required the constant presence of an operator at the button repeater to watch for breaks and to turn the handle at the right moment. It will therefore be readily surmised that an instrument, or a combination of instruments, which would dispense with the services of this operator, by automatically preserving intact the circuit of the sending station, at the same time allowing each station to break the other when desired, was much sought after.

Mr. Charles S. Bulkley has the credit of having invented the first automatic repeater. It was called an open circuit repeater, but as it has been obsolete for years I shall not describe its action here.

Mr. Bulkley imitated Professor Morse in the manner of keeping his invention a profound secret from curious investigators, by fitting up a labyrinth of wire coils around his instruments. But it was not long before other styles of automatic repeaters were invented by Farmer, Woodman, Hicks, Haskins, Milliken, Catlin, Toye, and a host of others, the majority of which repeaters, although quite efficient, never came into general use. Of these the Milliken, which was adopted as the standard automatic repeater of the Western Union Company, and the Toye repeater, which is quite extensively employed in Canada, are about the only repeaters now in general use. For this reason I shall limit the descriptions of the various repeaters to these two, more especially as they are widely different in their methods of performing a similar function.

Fig. 44 is a diagram of the connections of the Milliken repeater.

In the figure, the western, or No. 1 circuit is led to the tongue of transmitter T^1 and thence, when that transmitter is closed, to the battery B^1. The eastern circuit is led to transmitter T^1 and through battery B, also to the ground. It is seen that the armature of relay R^1 controls the transmitter T^1 by a local circuit shown by dotted lines, and that the armature of relay R^2 in like manner controls transmitter T^2. Relay R^1 thus can repeat into the eastern circuit at will, for at each motion of transmitter T^1 the eastern circuit is made or broken at the point X^1. In the same way relay

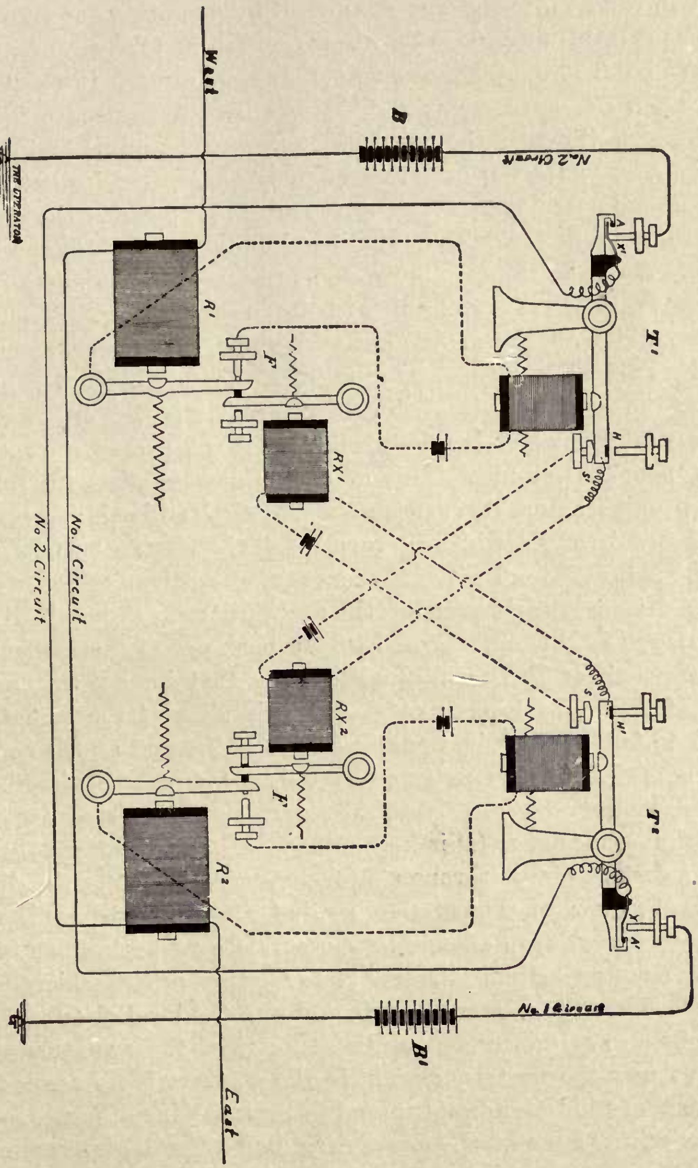


Fig. 44.—THE MILLIKEN REPEATER.

R^2 can repeat into the western circuit by operating the transmitter T^2, as it opens or closes the western circuit at the point X.

We see that there are also two other local circuits in the diagram, one from the extra relay RX^2 to the bar of transmitter T^1, and completed through the insulated screw S^1; and the other, from relay RX^1 to the bar of T^2, completed through the insulated screw S. These extra relays are supported in the position shown in the figure by brass standards. It is the function of each of these extra relays RX^1 and RX^2 to keep the armature of the adjoining line relay closed while its circuit is being repeated into. They do so in the following manner: Let us assume that the east opens his key. This allows the armature of R^2 to fall back, which action opens the local circuit of T^2, thus permitting that instrument to open, in doing which it removes battery B^1 from the western circuit and opens that circuit. This of course demagnetizes the relay R^1, and if unrestrained its armature would also fall back and open the local circuit of T^1, which in turn would break the eastern circuit at the point X^1, and give us the exact conditions which were described in the early part of the description of Fig. 43. But the armature of R^1 is not allowed to fall back, for at the moment that the transmitter T^2 was allowed to open, that instant the local circuit of RX^1 was broken at S, and this allowed the armature of RX^1 to fall back against the armature of R^1, and as the retractile spring of RX^1 is purposely made stronger than that of the relay R^1, it keeps the armature of R^1 firmly against its local contact point, and thus transmitter T^1 is kept closed, and by this means the route of the eastern circuit through T^1 is preserved intact, as the diagram shows, at the repeating station, so that when the east again wishes to close the western circuit he closes his own key, which by closing the eastern circuit attracts the armature of R^2, which by closing T^2 closes the western circuit, and also the local circuit of RX^1, thereby also withdrawing its armature from the armature of R^1. But as now the western circuit is closed, there is no tendency on the part of the latter armature to fall back. When the west wishes to repeat into the east, the above described action is simply reversed.

Supposing that the east now has his key open with the result shown in the diagram, when the west wishes to break he will open his key. This does not yet change the position of the instruments at the repeating station, as the western circuit is still open at X, transmitter T^2; when, however, the east next closes his key, in so doing he, of course, allows the relay R^2 to magnetize. This attracts its armature, which, by closing the local circuit, closes the transmitter T^2, and the western circuit is now closed at X, and the local circuit of RX^1 is closed at S. This action withdraws the armature of RX^1 from the armature of relay R^1, and the key of the western operator being open for the purpose of breaking, the western circuit still remains open. Therefore the armature of R^1 falls back, opening the local circuit of T^1, and breaking the eastern circuit at X^1. The eastern operator, now finding his circuit open, keeps his key closed, and thus the west is permitted to make any necessary remarks by causing relay R^1 to operate the transmitter T^1, which, as we have seen, breaks or closes the eastern circuit at X^1 at each motion.

In practice the transmitters are furnished with buttons, not shown in the diagram, by means of which the automatic repeating portions are cut off, thus allowing each of the circuits to be worked as a single wire from the repeating station.

I have said that the local circuits of RX^1 and RX^2 are broken at the instant that the respective main circuits are broken at X and X^1. In reality the local circuits at RX^1 and RX^2 are broken an instant before the main circuits, for the moment that the levers of the transmitters begin to move, that moment the local circuits of RX^1 and RX^2 are broken, whereas the tongues of T^1 and T^2 follow the contact screws until prevented by the bent arms AA^1, and by this arrangement the holding fast at the proper time of the armatures of R^1 and R^2 by the armature of RX^2 and RX^1 is insured.

In the transmitters used in the Milliken repeater, the bent arms are insulated from the tongues, and the bar from the screws H and H^1, so that any possibility of interference between the local and line batteries of RX^1 and RX^2 is removed. From this description

it will be observed that the action is in a measure mechanical, the armatures of the extra relays RX^1, and RX^2 holding the armatures of the line relays as firmly and promptly against their contact points at the proper moment, as would be possible for the finger of an operator to do; indeed, incomparably more promptly and firmly.

The Milliken repeater was used for a long time between Jacksonville, Fla., and Havana, on the Cuba cable, the repeating stations being at Punta Rassa, Fla., and Key West, a total distance of 560 miles, 320 of which is through a cable. The Milliken has, however, recently been supplanted on this route by the Johnston repeater.

The Toye Repeater.

As I have said, the operation of the Toye repeater is entirely different from the Milliken. It is considered much simpler. It certainly possesses an advantage over the Milliken, inasmuch as the instruments used in its operation are ordinary line relays and continuity-preserving transmitters, and need but two local batteries. The Milliken repeater requires four local batteries in its operation. The Milliken, however, has the reputation of being the most generally efficient of repeaters.

Fig. 45 shows the connections of the Toye repeater. The main circuits are first led from the line through the posts of the transmitters, thence to the tongues of those instruments, to the line relays, the batteries and ground. The bar of each transmitter is connected with a rheostat, the object of which will shortly be explained.

I will assume that the west wishes to repeat into the eastern line. He has opened his key, which opens R^1 and permits its armature to fall back, opening the local circuit of T, and breaking the eastern circuit, as seen in the figure at the point X^1.

Just prior to the moment, however, that the eastern circuit was broken at X^1, the battery B was shunted, *via* the bar or lever of T into the rheostat H, as shown in the diagram. Thus the relay R has not lost its magnetism, and its armature is still retained against its contact point, thereby keeping the transmitter T^1 sta-

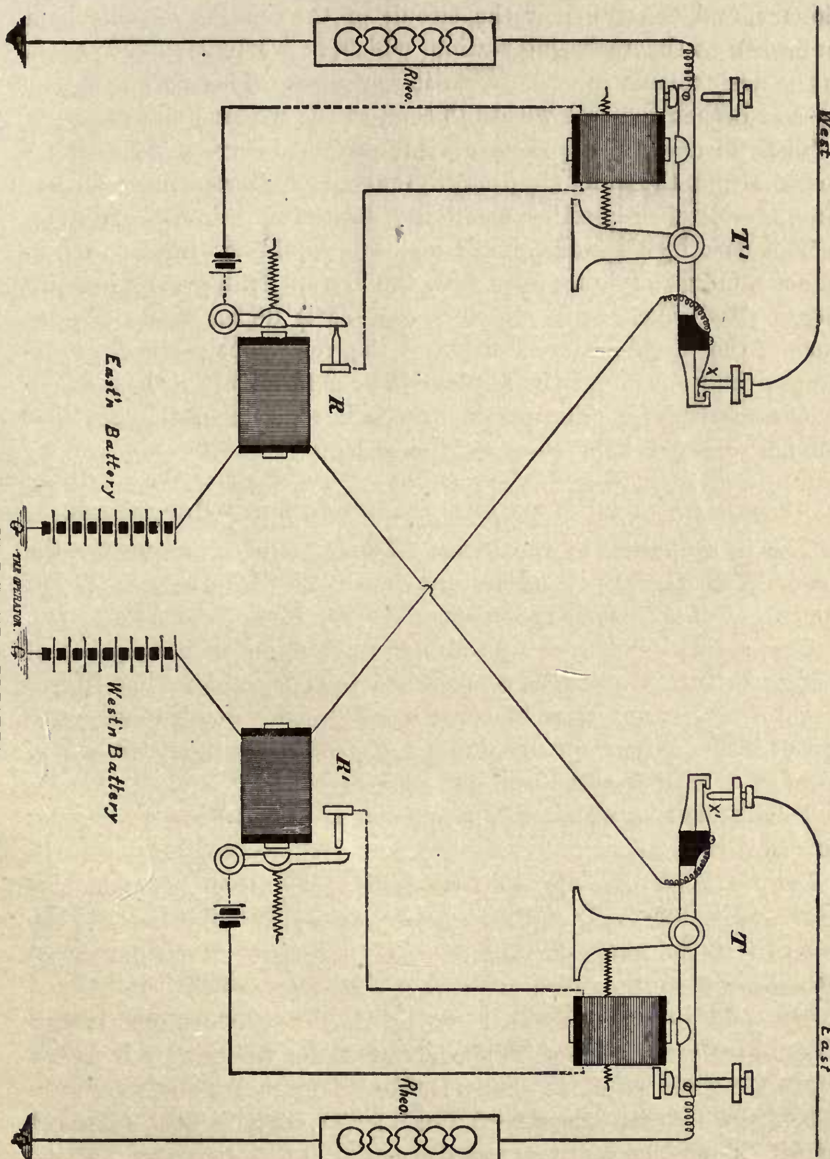


Fig. 45.—THE TOYE REPEATER.

tionary, and consequently the circuit of the sending office is kept unbroken at the repeating station, which, as we have already seen, is the desideratum in all automatic repeaters. This action is also reversed when the east wishes to send to the western circuit.

The resistance of the rheostats is adjusted to correspond with the resistance of the line circuits, so that the batteries meet with a similar resistance in either position of the transmitters.

This description makes it plain that it would be difficult to construct a more simple repeater than the Toye. It, however, has two slight drawbacks, one of which is, that as it depends on the presence of the main batteries to keep the relays magnetized at the proper time, it can only be employed at the terminals of lines, where such batteries are. The other drawback consists of the fact that the batteries are kept constantly closed.

Combination Duplex and Single Circuit Repeaters.

The introduction of the Stearns Duplex, and subsequently the quadruplex systems of telegraphy, dispensed with the services of many sets of automatic repeaters.

These multiplex systems did not render the wires capable of being worked at any greater distance than heretofore, but it was found a very easy matter to cause one duplex or quadruplex set to repeat into another quadruplex or duplex set, without the use of any of the regular automatic repeaters.

The manner in which this repetition is effected is very simple; but, as it may not be generally known, I shall herewith describe it.

Let us take, for example, the cable quadruplex circuit between New York and Sydney, C. B., with the quadruplex repeaters at Bangor, Me.

At the repeating station, Bangor, there are two quadruplex sets. One of these works direct with New York, the other with Sydney.

I can, I think, simplify the description if the reader will take a piece of blank paper and roughly draw on the left-hand side of the paper a neutral relay and a transmitter, and immediately beneath these instruments, a polar relay and a pole changer, and call this the New York set.

On the opposite side of the paper draw, in the same way, another neutral relay and transmitter, a polar relay and pole changer, and call this the Sydney set.

Now draw lines representing a local circuit from the contact points of the neutral relay of the New York set to the magnet of the pole changer of the Sydney set, and insert a local battery. This gives the neutral relay control of the pole changer.

In the same manner give the neutral relay of the Sydney set control of the pole changer of the New York set.

Draw lines again from the polar relay of the New York set to the transmitter of the Sydney set, and in like manner connect the armature of the polar relay of the Sydney set with the transmitter of the New York set.

It is now seen that when the neutral relay of the New York set is operated, its armature operates the pole changer of the Sydney set, and when the neutral relay of the latter set is worked, it operates the pole changer of the New York set; that the polar relay of the New York set operates the transmitter of the Sydney set, and the polar relay of the latter in turn operates the transmitter of the New York set.

In other words, the armatures of the different relays act simply as keys to operate the various pole changers and transmitters of the opposite sets.

I think it will now be quite plain to the reader that when, for instance, the operator in the New York office, who may be sending on the second side, manipulates his transmitter, his signals will operate the neutral relay of the New York set in Bangor, which in turn, by operating the pole changer of the Sydney set in Bangor, repeats the signals on to the Sydney office, and *vice versa.*

Of course a duplex set can be caused to repeat into another duplex set in the same way.

It will be noticed by the foregoing that the No. 1 side of each set is made to repeat into the No. 2 side of the other set.

This arrangement is not absolutely necessary, as the first side of one set could be just as readily made to repeat into the first side of the other set.

The first-mentioned arrangement is, however, the one generally adopted, probably to neutralize any atmospheric condition which would perhaps tend, on a long circuit, to make one side work better than the other.

It is quite frequently found that all of a quadruplex set is not required for the handling of business between certain points, and that therefore half of a set, that is one side of it, can be spared for other purposes.

Thus there is a quadruplex circuit between New York and Elmira, one side of which is set apart for the local business, while the other side is connected with a single wire to Bradford, Pa.; and there are many other similar circuits.

The utility of the quadruplex system is here seen, inasmuch as it saves one wire for the distance covered by the quadruplex system—for instance, in the case referred to, a wire between New York and Elmira.

A combination circuit of a quadruplex and single circuit requires an automatic repeater at the point where the junction is made, and several arrangements have been devised for this purpose, one of the first of which, known as the Waterbury repeater, I shall here describe.

In Fig. 46, *T* and *N R* are, respectively, the transmitter and neutral relay of the second side of a quadruplex set, from which all but the local connections have been omitted. *R T* is a repeating transmitter; *R R* is a repeating relay.

The single wire is led, as may be seen in the diagram, through the repeating relay to the tongue of *R T*, and thence to the battery and ground.

There is also an extra circuit shown by dotted lines from *R R* to the bar of *R T*, in which is inserted a local battery, also as shown.

When the transmitter *R T* is open (as it will be when the neutral relay *N R* is open), this extra circuit is completed through *R R*, and *via* the bar and tongue of the transmitter at x', so that whenever *R T* is open, the repeating relay will be kept closed.

It is, of course, understood that the operator at the distant end

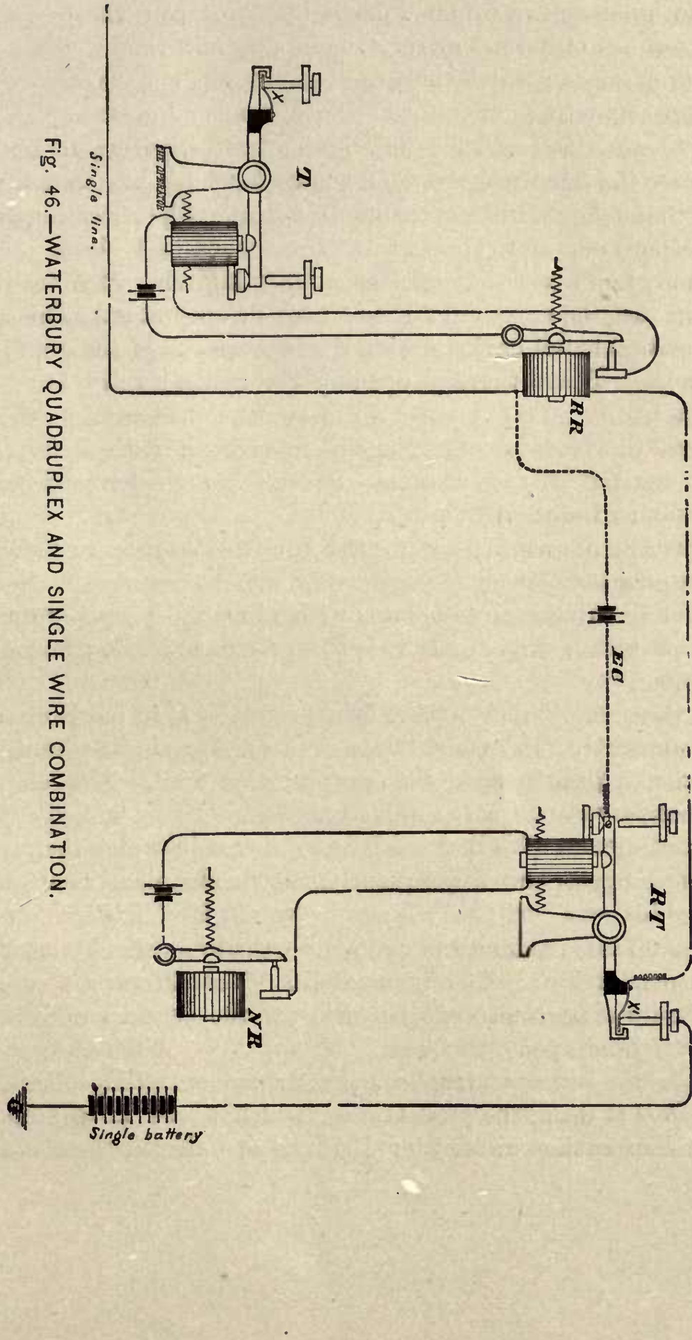


Fig. 46.—WATERBURY QUADRUPLEX AND SINGLE WIRE COMBINATION.

of the quadruplex, whom I shall hereafter call the quadruplex operator, can only send or receive one way at a time.

The manner in which this arrangement acts is as follows: —

Suppose that the operator at the distant end of the single wire, whom I shall refer to as the Morse operator, wishes to send; in that case the quadruplex operator must keep his key closed, which we are all aware will keep the neutral relay at the repeating station closed, as seen in the diagram. Now when the Morse operator opens his key that action opens the repeating relay *R R*, for it may be seen that the extra circuit is at present open at x'. This allows its armature to fall back, opening the local circuit of the quadruplex transmitter *T*, and thereby opening the neutral relay at the distant end.

When the Morse operator again closes his key, thus closing the single wire circuit, the armature of *R R* is attracted, and thereby again closes the transmitter *T*. Thus as often as the Morse operator opens or closes his circuit, the relay *R R* opens or closes the quadruplex transmitter.

When the quadruplex operator wishes to send, he simply operates his transmitter, which in turn opens or closes the neutral relay *N R* at the repeating station.

This action, by allowing the armature of *N R* to fall back, opens the transmitter *R T*, which thus cuts off the single-wire battery from the single wire at x', thus opening that wire. The relay *R R* does not, however, open at this time, for, as I have already shown, the extra circuit, with its local battery, comes into play the moment that *R T* opens, and, consequently, the quadruplex operator does not get his own writing back, as he would if *R R* were not kept closed. When the quadruplex operator again closes his transmitter the neutral relay *N R* is again closed. This in turn closes *R T*, again connecting the single battery with the single wire and closing that circuit.

In this way the quadruplex operator, by controlling the neutral relay *N R* at the repeating station, which, as we have seen, controls the repeating transmitter *R T*, can operate the single wire at

will, for at each motion of *R T* the single wire's circuit is opened or closed at the point x'.

This arrangement has been found very serviceable in good weather, but during stormy weather its action is not so satisfactory. This is owing to the fact that the increased magnetism in the single-wire relays, in wet weather, necessitates the pulling up of the relay spring to such an extent that the local battery of the circuit becomes unable to hold the relay closed against the increased tension of the relay spring, and hence the quadruplex operator gets his own writing back.

It may have occurred to the reader that this function could be performed by the use of one-half of either of the automatic repeaters which I have previously described, and such is the case.

There are many circuits on which one-half of the Milliken or Toye repeaters is used for this purpose with entire success.

It is well known that there are a great many quadruplex sets leased to broker firms, two firms generally being assigned to one set, each firm using one side of a set.

In such cases the quadruplex sets are stationed in the main offices of the company, while a single wire known as the "short or branch wire" is run direct from the quadruplex sets to the brokers' offices.

A repeating arrangement is also essential to the working of this plan, and a number of different methods are employed, including a modification of the Toye and other repeaters.

The method employed in New York city is known as the D. R. Downer repeater—shown in Fig. 47—a very simple and effective arrangement, which I shall proceed to describe.

In the figure, *T* and *N R* are the transmitter and neutral relay of a quadruplex set. They may, however, be supposed to represent equally well a pole changer and polarized relay. *R T* is a repeating transmitter.

It is seen that the neutral relay has control of *R T* by means of the local circuit shown, and that the broker's single wire has control of the quadruplex transmitter *T* by the route as represented in

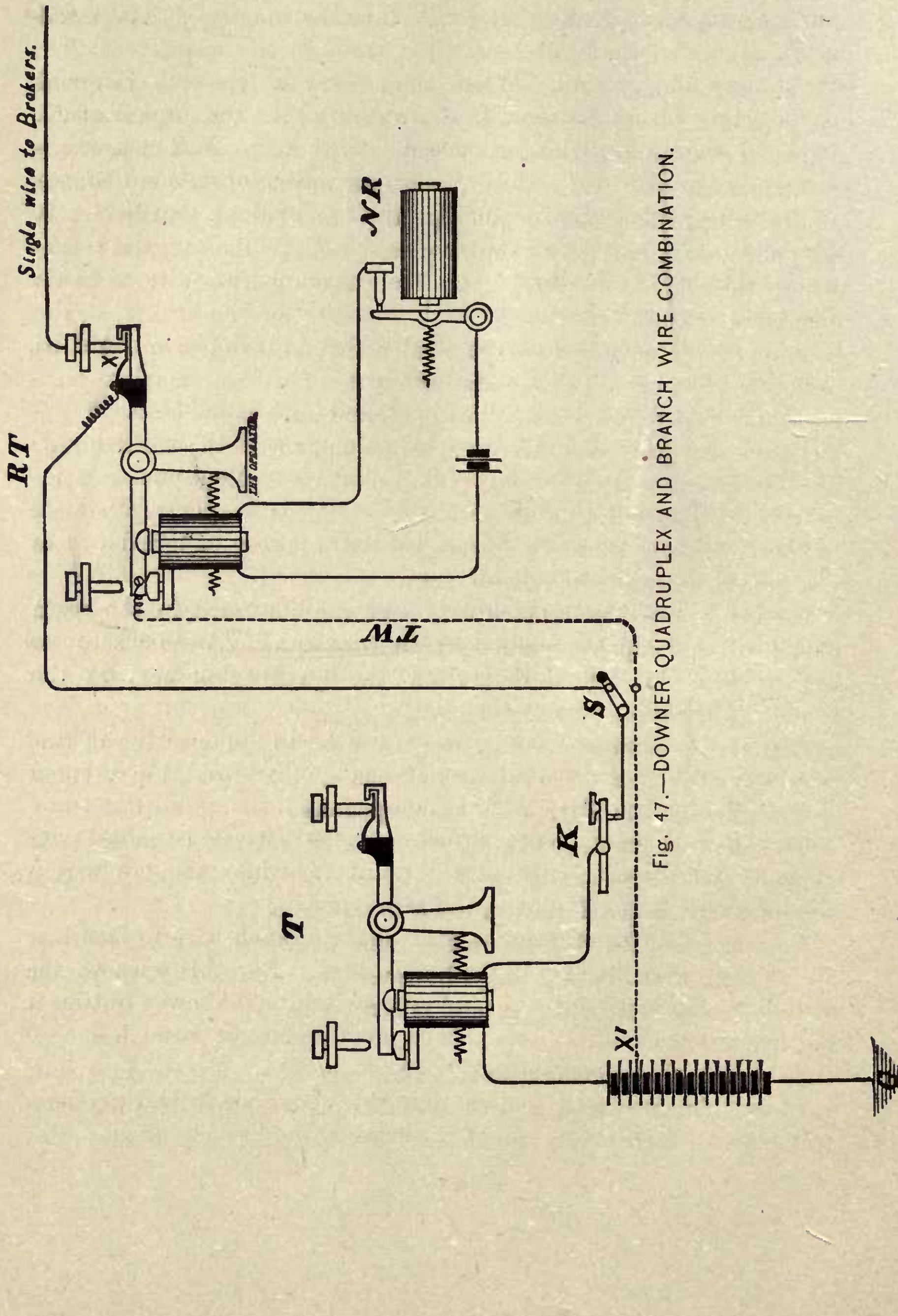


Fig. 47.—DOWNER QUADRUPLEX AND BRANCH WIRE COMBINATION.

the diagram through the post of *R T*, to the tongue of that instrument, thence to the button switch *S*, through the magnet of *T* to the battery and ground. When the broker at this end (referring to diagram) wishes to send, it is necessary that the broker at distant end should keep his key closed. This keeps *N R* closed, and consequently also *R T;* thus the broker has unobstructed control of the quadruplex transmitter *T*, for it is evident that when he opens his key it must open the transmitter *T* by breaking the circuit of the branch wire battery. On the contrary, it is quite as essential that, when the distant broker is sending to the broker at this end, the quadruplex transmitter *T* at this end should be kept closed, and that object is effected as follows:—

When the distant broker desires to send, he opens his key; this opens *N R* in the diagram, this in turn opens *R T*, which breaks the branch wire circuit at the point *X*, and opens the sounder in the broker's office at this end. At the moment, however, that the broker's wire is opened at *X*, another extra circuit, *T W*, shown by the dotted lines, is brought into play, namely, *via* the bar of *R T* to the point *X'* in the battery, through this small portion of the battery, which is known as the "tap," to the magnet of *T* and back to the bar of *R T* by way of the tongue of that instrument. By this means it will be observed that the quadruplex transmitter is kept closed at the right moment, without the use of any additional local battery. When the distant broker again closes his key or transmitter, the neutral relay *N R* is again closed, the repeating transmitter *R T* is thereby also closed, and the battery is placed once more to the branch wire at the point *X*, while the tap wire is disconnected at that point at the same time.

It is sometimes necessary to cut off the branch wire to facilitate the testing or balancing of the quadruplex. For this purpose the switch *S* is inserted. By turning the switch to the lower button it may be noticed that there is a short metallic circuit formed, enclosing the key *K* and controlling *T*.

It is, I suppose, well known that the above described arrangement dispenses with the use of one wire to the branch office.

In some cases, however, the repeating device is not used, but instead two short wires are furnished, one of which is in direct connection with the transmitter, and the other with the neutral relay, both wires being grounded at the branch office.

In some main offices one-half of the Toye repeater is also used to perform the necessary repeating work from the quadruplex to a branch wire.

By reference to Fig. 47 it will be seen that this can be done very easily, as follows : Remove the tap wire *T W* from the battery at *X'*, and conduct it through a rheostat to the ground. No other change is necessary. Of course the resistance of the rheostat will require to be made equal to the limited resistance of the branch wire.

The only advantage that I know of in the Downer arrangement over the Toye, for this purpose, is that mentioned in the description of the Toye repeater, namely, that the entire battery is not always kept closed.

By the Downer plan the greater portion of the battery is open half the working time.

I shall now bring this chapter to a close by giving one or two hints on the practical management of repeaters of the latter class.

In the first place, it should be a rule to see that the contact points are cleaned regularly, and that the local batteries are kept up to a standard strength. It is a good plan to test the strength of the local batteries occasionally, by withdrawing the armature of the instruments against the attractive force of the magnets. When there is a decided sign of weakening, the locals should be at once renewed.

It is a somewhat common occurrence to find that the writing on the neutral relay is being repeated back on the transmitter.

This fact is sometimes brought to your attention by the statement of the distant end that he is getting his own writing back.

This effect may be produced by one of several causes. For instance, the branch office may have his key open, or the transmitter points at *X* in Fig. 47 may not be making proper contact, or they may need cleaning. Your own key may be open, or the battery may have failed. To locate the trouble, first see that the repeating

transmitter is acting properly, and that the points are clean. File them. Turn the button switch to the left. If this closes the transmitter, it shows that the local portion of the battery is all right. Next take a piece of wire and attach one end of it to the post of the repeating transmitter, the other end to a ground. There are always plenty of good grounds around a quadruplex set. If this closes the quadruplex transmitter, it proves that your battery is in order, and that the circuit is open between you and the branch office. Care should be taken, however, to notice that the transmitter is closed with somewhat more than the usual strength, because it is possible that the battery may have partially run down, and while too weak to close the transmitter when the full resistance of the branch wire was in the circuit, is still strong enough to close the transmitter with the branch circuit cut off. These tests can be made within one minute when one is familiar with the mode of proceeding.

Besides those repeaters which I have described, and also those that I have referred to, there have been other forms of repeaters invented. For instance, repeaters that allow one wire to repeat into two distinct circuits, and give each of those two circuits the power of automatically breaking the sending circuit. Such repeaters have been termed "three-corner repeaters."

Mr. R. C. Edwards, of New York, has recently invented an octuplex repeater, which enables the sending circuit to repeat into eight distinct circuits, and also allows each of those circuits to automatically break the sending circuit.

There may also be other systems which have not come under my observation.

I have myself invented a very simple multiple repeater, by means of which one circuit can repeat into one, fifty, or a hundred or more other circuits, each of which other circuits can automatically break the sending circuit, or it can be arranged so that one of a system of, say fifty or one hundred circuits, can repeat into fifty or one hundred circuits of another system, and any one of the latter system can automatically repeat into all of the former system.

THE
WHEATSTONE AUTOMATIC TELEGRAPH.

BY WM. MAVER, JR.

A general interest has been created among operators concerning the Wheatstone automatic telegraph since its adoption by the Western Union Telegraph Company as its rapid telegraph system. A desire having been evinced to learn more about its manner of working, I shall endeavor in this chapter to give a detailed description of the method of its operation.

It is, I suppose, generally known that the Wheatstone automatic system differs from the American Rapid Company's automatic, or any other system of fast automatic telegraphy in this country in which the Morse alphabet is used, inasmuch as it is what may be termed a mechanical automatic telegraph, while the others are chemical automatic systems.

The chemical systems that most resemble the Wheatstone are those that use prepared perforated paper for the purpose of transmitting signals; for instance, the American Rapid system, which was fully described in the columns of *The Operator* some time ago.

In the latter system the perforated paper is passed over a metal cylinder, which is a continuation of the main circuit, and two needles, or styles, connected with the negative and positive ends of batteries respectively, are placed on the top of the paper in such a position that when the punctured portions of the paper pass, the needles are allowed to connect with the cylinder beneath the paper, and thus permit a positive or a negative current to flow to the line, according to the situation of the punctures. This is called direct contact.

At the receiving station of this system there is another metal cylinder (which is also a part of the main circuit), over which passes a

ribbon of chemically prepared paper. Resting on this paper is a needle, likewise a part of the circuit. As this paper is moistened with a chemical preparation, it constitutes a good conductor, and when a current of electricity is sent to the wire from the sending end it passes through the needle and the paper to the cylinder and ground. While the current is thus passing through the paper, a chemical decomposition of the ingredients composing the solution in which the paper has been previously soaked takes place, and in consequence a mark, varying in color according to the constituents of the solution, is recorded on the paper as long as electricity is allowed to flow through the circuit.

Thus, by varying the duration of the current on the line, which is the function of the perforated paper, dots and dashes can be signaled as required.

In the Wheatstone system the perforated paper serves to send currents of either polarity to the line, and also governs the length of the mark recorded at the distant end—but in an entirely different manner from that just reviewed.

Beneath and pressing up against the perforated paper in the Wheatstone system are two needles, or small levers, the lower ends of which are connected by springs and other mechanism to a delicately constructed pole changer.

When there are no punctures in the paper passing above the small levers, the latter are prevented from moving to their full extent, and thus fail to actuate the pole changer. When either of these needles comes to a hole in the paper it passes through it and makes its full motion, and so moves its connections that a certain pole is placed to the line.

At the receiving end a polarized relay is placed, whose armature responds to the changes of polarity at the sending end, and operates an inking apparatus, which, when in a certain position, records a mark on the receiving paper.

This will probably be sufficient to show the distinction between a mechanical and chemical automatic system. Each of these respective systems has its advantages and disadvantages, but as it is

not intended in this chapter to discuss these, I shall merely mention one or two of the characteristic features of each.

In some of the chemical methods there seems to be almost no limit to the rapidity with which signals may be sent and recorded, as, to a certain extent, it simply depends on the frequency with which the line can be charged and discharged. This is one of its advantages. One of its disadvantages lies in the fact that occasionally the perforations in the paper are not clearly punctured, and thus small pieces of paper intervene between the direct contact needle and the cylinder, and thereby cause confusion.

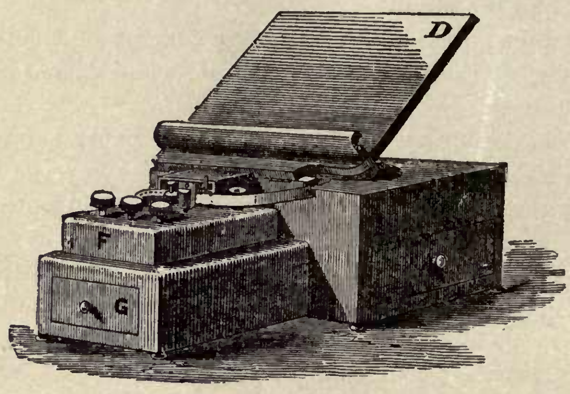


Fig 48.

The speed at which a mechanical system can be operated is limited by the rapidity with which the electro-magnet can be charged and discharged, and overcome the inertia of its armature, so that distinct signals shall be recorded. One of the advantages of the latter system, and it is a valuable one, is that the receiving signals are received on blue stiff paper, in clear Morse characters. Another is that as the speed at which signals arrive by this method is not beyond the rate at which the receiving instrument clerk can follow them, any errors which may occur are at once detected and corrected.

It may, perhaps, aid the reader to an understanding of the working of the Wheatstone system to remember that the operation of

the various parts of its mechanism all tend to the transmission and reception of the Morse characters. What operators do by the hand this machinery does automatically. We are all aware that when we are sending on a polar duplex, or the polar side of a quadruplex (the number one side), to make a dot we have to cause the key to make two motions, one down and one up. In doing so we have changed the polarity of the current twice. By closing the key, which is, of course, equivalent to closing the pole changer, we send a current to line, which attracts the armature of the distant polarized relay to the local contact point. By opening the key again, we place a different pole to the line, and it repels the armature from the local contact point. To make a dash we simply allow our fingers to linger an instant longer on the key when it is closed. To make the space we keep the key open a moment. What we thus do by the guidance of our faculties, the automatic is required to do by the arrangement of its component parts. By recollecting what is required of the mechanism, we may be the better able to comprehend the manner in which it accomplishes this purpose, when it is explained.

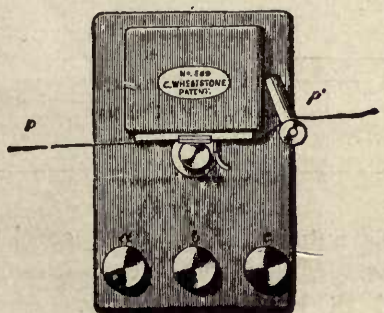


Fig. 49.

Let us suppose that when we close the key on the polar duplex or quadruplex, we send a positive current to the line, and that the polarized relay is so arranged that it is the positive current that attracts the armature of the relay to the local contact point, and

that when we open the key we place a negative pole to the line, which repels the armature from the local points.

Now, if we attach a pen to the armature and cause a strip of paper to pass in close proximity to it, if the key is closed we shall have a mark on the paper until we again open the key. This is similar to what occurs in the Wheatstone system by the combined operation of the perforated paper, which acts the part of the operator's fingers, inasmuch as it controls the levers under the paper, and the transmitting mechanism. These levers correspond to the Morse key, as they actuate the pole changer, which latter in turn operates the distant polarized relay with its inking attachment, as will be explained in the detailed description of the Wheatstone transmitter and receiver.

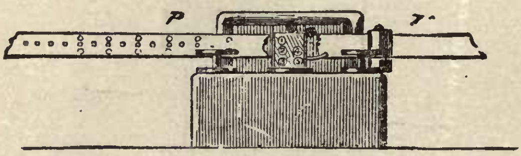


Fig. 50.

The Wheatstone automatic apparatus consists of three parts, namely: the perforator, the transmitter, and the receiver.

The perforator is the instrument by means of which the message is prepared for transmission, and is shown in full in Fig. 48. It consists of three distinct boxes, the largest of which supports the stand *D*, on which messages intended for preparation are placed for the convenience of the punching operator. It also contains the paper to be punched. The smallest box *F* contains the punching apparatus proper. Box *G* serves to support the latter box, and to receive the residue of the perforations which rapidly accumulate. The paper which is seen issuing from the largest box is of a stiff white pattern, and has been previously prepared for punching by having been dipped in olive oil, so as to dispense as much as possible with the paper dust, which, unless the paper is so prepared, is found to cause trouble by clogging up the punching apparatus. The oil also serves to lubricate the machinery of the perforator.

Figure 49 is a top view of box *F*, Fig. 48. The buttons or discs *A B* and *C* are mechanically connected to three levers or keys beneath the cover of the box, and these levers are again respectively connected in such a manner to three, one, and four sharp, hollow cylinders, that when either of the discs *A*, *B* or *C* is depressed, the corresponding sharp cylinder is urged forward through the paper ribbon, cutting clear round holes therein.

Fig. 50 shows these hollow cylinders as arranged.

The depression of disc *A* causes three of these cylinders to punch the paper in one vertical line (see Fig. 51), which corresponds to a dot; *B* causes one only to punch (Fig. 52), which is the spacing mark; *C* causes four of them to perforate the paper (see Fig. 53), which correspond to the dash. There is another and important piece of mechanism in this box, not shown in the diagram. It consists of a small star wheel, the teeth of which fit closely into the central or

Fig. 51.

Fig. 52.

Fig. 53.

space holes. The same action that impels any of the punching cylinders forward jerks the star wheel around, and it is thus made the medium for carrying the paper along as it is perforated. The punching operator is provided with two small iron mallets tipped with rubber, by means of which he depresses the discs. In practice the dot and dash discs have a dot and dash engraved on them, but, of course, this is not necessary to distinguish them after a few hours practice. The dot disc is on the left side, the dash disc on the right side, and the space disc is in the middle. To make the letter *C*, for instance, the dot disc is struck twice in succession, then the space disc, and again the dot. The spacing disc is struck twice between words, and once between each letter. This method of punching entails a considerable amount of manual labor, and soon becomes very tedious. The most expert punchers do not maintain a speed of more than thirty-five words per minute for any length of

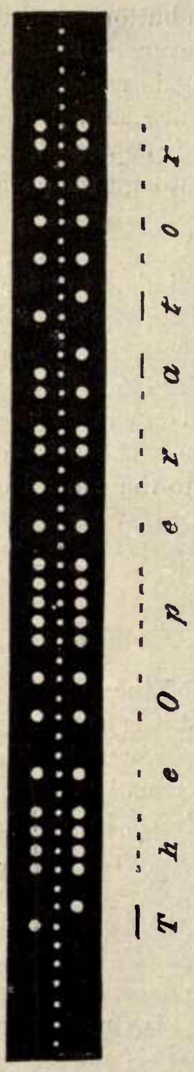


Fig. 54.

time. As it would be impracticable to make a dash long enough for the American Morse signal for the letter L, it has been given the characters of two dots and two dashes.

Fig. 54 shows the words *The Operator* prepared for transmission in the manner above described.

The Wheatstone transmitter, Fig. 55, is contained in a brass box about eight inches long, five inches high, and three wide.

Fig. 56 is an exterior view of the box, showing the transmitting apparatus proper.

The paper is represented by the straight line P, and moves in the direction indicated by the arrow.

The levers S and M are kept in their upright positions by the retractile springs shown. These levers are so adjusted by the screw posts F and F', that the lever M is allowed to go slightly farther to the right than the lever S. This apparently trifling arrangement should be remembered, as it will be seen farther on that it serves a useful purpose.

R is a beam of ebonite or other insulating material, supported by a pivot in its center, running backward into the box. This pivot is connected with the clock-work contained in the box, in such a manner that when the clock-work is in operation it imparts to the beam a rocking motion, similar to the walking beam of a steamboat. An upward tendency is given to the levers S and M by the springs S and S' attached to the crank levers A and B, but the extent of the upward motion of the levers S and M is regulated by the metal pins 1 and 2 inserted in the beam, and also by the prepared paper P.

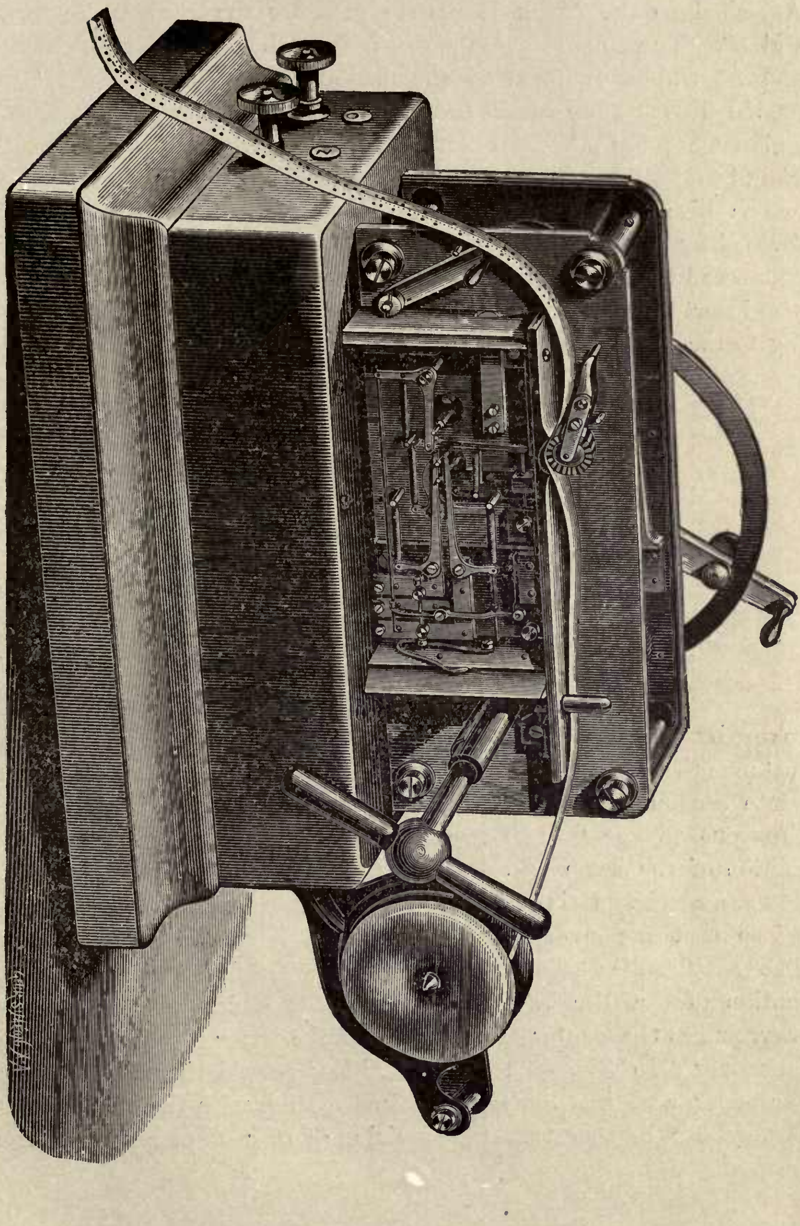


Fig. 55.—THE WHEATSTONE REPEATER.

Attached to the crank levers *A* and *B* are the straight levers *H* and *H′*. The ends of these pass through the projecting pieces *P* and *P′*, which are fixed to the movable disc *D*. *H* and *H′* are provided with small collars or collets *K* and *K′*, which prevent their ends from going beyond a certain distance through the projections *P* and *P′*.

The disc *D* is pivoted to the frame-work of the box, and is divided by an insulating material into two parts, one of which is connected to the ground, and the other to the line. Metal pins are also inserted in this disc, and on one or other of these pins, according to the position of the disc *D*, the crank levers *C* and *Z* are made

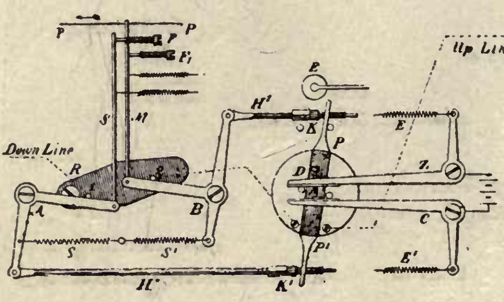


Fig. 56.

to rest by the action of the retractile springs *E* and *E′*. In the present instance the beam *R* has moved upward, thus permitting the lever *M* to ascend under the influence of spring *S′*. The lever *H′* has thus pushed the disc *D* over to its present position. The same motion of the beam has, by aid of the pin 1, pushed the lever *S* down, and this motion of lever *S* has withdrawn the lever *H* from *P′*, so that the lever *H′* was unopposed in pushing over disc *D*. The small roller *E*, being pivoted on a tension spring, aids the motion of the disc in this wise: when the piece *P*, going either way, passes the center of the roller *E*, the latter gives the disc *D* a jerk over. In Fig. 56 the lever *M* has passed through a hole in the paper, and thus has made its full motion with the above effect. It may also be seen that this position of disc *D* places a positive

pole to the line. If, now, the beam make another motion whereby the lever *S* is permitted to ascend, and the lever *M* is made to descend, it may be seen that the collet of lever *H* will be driven against the piece *P′*, and as the collet of the lever *H′* is now withdrawn from *P*, the position of the disc *D* is changed, and the negative pole sent to the line, as shown in Fig. 57. Thus we can see, presuming there is no paper passing above to limit the motion of the levers *M* and *S*, that as often as the beam is moved up and down, the polarity of the battery is changed.

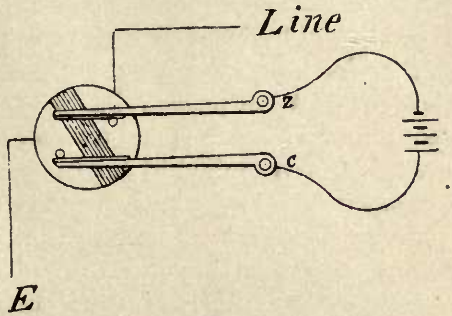
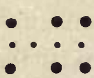


Fig. 57.

Directly under the paper *P*, in Fig. 56, is a small star wheel, not shown in the diagram. This wheel is geared with the clock-work also, and in such a way that when the beam *R* makes one motion, the star wheel moves around the space of one tooth. The teeth of this star wheel, as in the punching apparatus, fit into the central holes of the prepared paper, and as it revolves carry the paper forward.

Let us now follow the operation performed by this apparatus in making the letter *R*, as seen in Fig. 58, namely, two vertical holes, a blank, and a series of two sets of two vertical holes. As the right hand end of beam *R* moves upward, the lever *M* passes up through the topmost hole in the paper, as it appears in Fig. 58, or the hole nearest the frame of the box. This, as I have already said, sends a marking current to the line, to which the armature at

distant end responds. The right end of the beam moves downward ; the left end moves upward, and with it the lever *S*. At the same time the star wheel moves the paper forward one space, and this movement of the paper brings the lowest of the two vertical holes now opposite the lever *S* (for it will be remembered that the lever *S* is adjusted a little to the left of *M*), which passes through that hole. Thus the polarity is again changed, and the inker is withdrawn from the paper at the distant end. The beam makes another motion, and the star wheel carries the paper one tooth forward ; but it is seen that the lever *M* meets with no hole, and its upward course is, therefore, blocked by the paper, and the pin 2 moves up unfollowed by *M;* as the lever *M* consequently has not made its full motion, the lever *H'* has not pushed the disc *D* over, and thus the same pole is continued to the line, and a blank space is left on the receiving paper. Another motion of the beam brings the lever *S* up to the paper, but it, too, in the same way, is prevented from making its full phase, and the disc *D* remains as it was, which further increases the space on receiving paper. A further motion of the beam now brings the lever *M* again up to the paper, and also opposite the topmost hole of the second series of holes, which the star wheel has advanced. The lever thus makes a full movement, and this sends a marking current once more to the line. Again lever *S* is brought up to the paper, and, also finding a hole, passes through it, again changing the polarity, and the marker is withdrawn ;



R.

Fig. 58.

A.

Fig. 59

thus another dot is recorded. The polarity is again changed twice as before, and another dot is marked, which now gives us on the receiving paper a dot, a space, and two dots.

The diagonal position of the dash perforations simply reverses the action necessary for a spacing current. Take, for instance, the let-

ter *A*, Fig. 59. The upper hole allows a marking current to be sent. Immediately the lower hole reverses it, and a dot is recorded. The second upper hole sends another marking current to line, and, as owing to the position of the next lower hole the beam will require to make two motions before the lever *S* reaches it, the marking current continues to the line, and a dash is allowed to be recorded on the receiving paper.

Of course these actions take place very rapidly, so much so that when the apparatus is at full speed, namely, about 250 words per minute, it is impossible to follow the motion of the levers. This statement may be better understood when it is reflected that at this rate of speed the levers move about 4,000 times per minute.

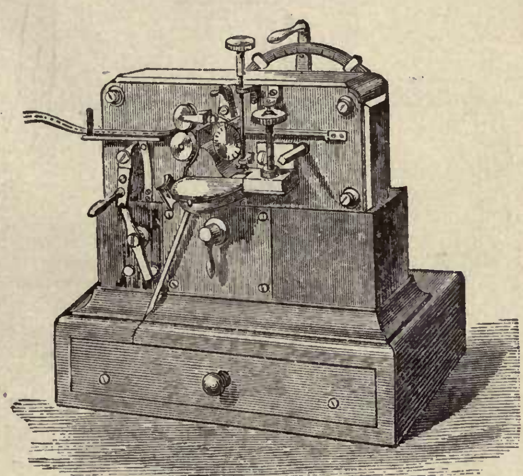


Fig. 60.

The Wheatstone Receiver.

The receiving instrument is contained in a brass box of about the same dimensions as the transmitter. See Fig. 60. Within the box are the polarized relay, previously mentioned, and the clockwork, hereafter referred to, which is operated by a spring.

The receiving paper passes over a roller which is in close proxim-

ity to the inking apparatus. The roller is actuated by the clock-work, and is the means by which the receiving paper is carried along.

The instrument is supplied with a governor, which regulates the speed of the clock-work.

Fig. 61 is a diagram of a part of the interior of the receiver.

P is a permanent magnet, in the ends or poles of which semicircular notches are made, into which the armatures of the polarized relay *M* are loosely fitted. *A* is an axis to which these

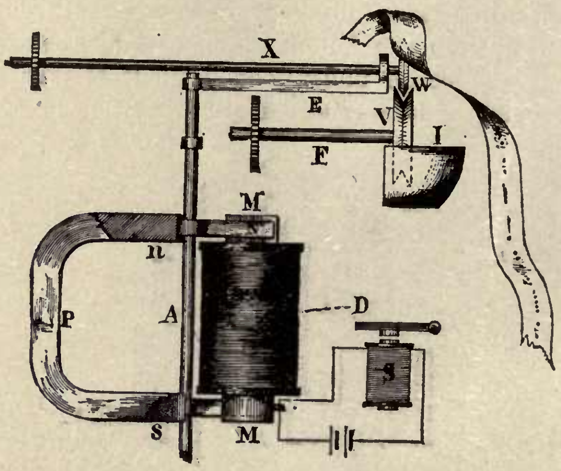


Fig. 61.

armatures are fixed. It extends above and below the electro-magnets. At its lower end connections are arranged for the operation of a local sounder *S*, which is used when the circuit is switched from the automatic to manual working. The upper extension of the axis *A* is bent in the manner shown. The poles of the electro-magnets *M* are placed opposite each other. One of the upper poles of *M* is omitted in the diagram to show the position of the armatures between the poles. The armatures oscillate between these poles in response to the changes of polarity at the distant end. As the extension *E* is also attached firmly to the axis *A*, it is evident that its motion must correspond to that of the armatures. When

there is no current on the line, and when the armatures are properly adjusted, they remain on whichever side last placed, in the same manner as the armature of the quadruplex polarized relay.

H is the axle of a cog wheel which is geared with the clockwork. To the right end of this axle, which protrudes through the frame work of the box, is attached a small wheel *W*, which rotates opposite the center of the roller, over which the paper is seen passing in Fig. 56. This small wheel also rotates within, but does not touch the groove of another wheel *V*, which revolves in an ink well *I*. In this groove sufficient ink is brought up by capillary attraction to the wheel *W* to keep its edge supplied without friction.

The axle *X* is given a slight tension toward the up-curled end of the extension *E*. There is a small notch in this up-turned end through which the axle *X* passes. This slight support is all that the axle receives in addition to that from its cog wheel.

When a negative or spacing current is placed to the line the extension *E*, moving, as I have said, in unison with the armatures, holds back the axle *X*, and, consequently, the wheel *W*, from the receiving paper. When a positive or marking current is sent to the line, the extension *E* is withdrawn from the axle *X*, and thus the wheel *W* is allowed to touch and mark the paper.

The polarized relay being practically inaccessible within the box, the armature is adjusted by means of apparatus placed outside of the box.

The play of the armatures, and likewise the marking wheel, is very limited, being about $\frac{1}{24}$ of an inch. This is necessarily so, on account of the rapid motions made when the apparatus is working at full speed. For the same reason all of the above mechanism is of very light construction, more so than the diagram would, perhaps, indicate. It may be further stated, as showing the need of delicate apparatus for fast working, that the sounder *S* in the local circuit, which is adjusted as ordinarily, ceases to record intelligibly after the speed exceeds say 125 words per minute, which is owing chiefly to the fact that its armature is unable to travel the distance to which it is adjusted, in the now diminished time.

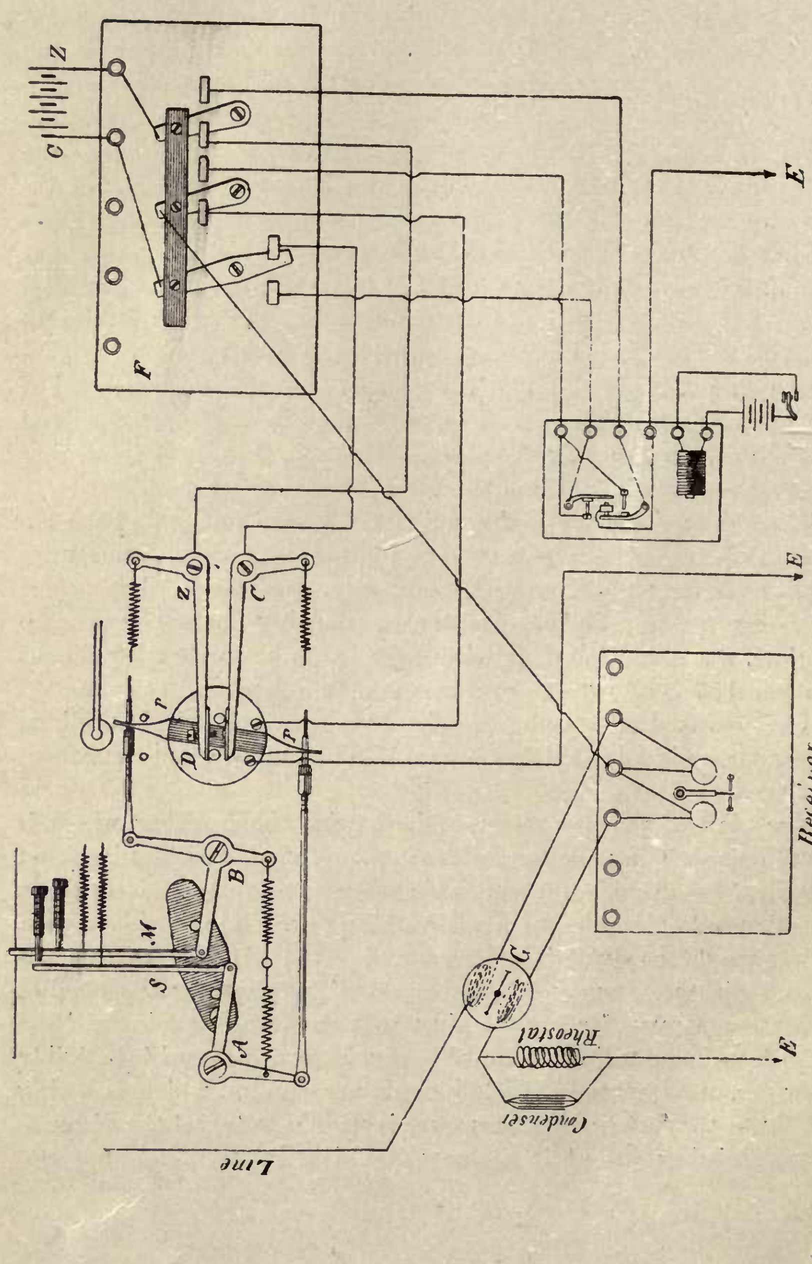


Fig 62.

The Wheatstone automatic system may be worked on a single or duplex wire. The foregoing description of the transmitter and receiver applies to the actions that take place when it is worked as a duplex. On the Western Union lines it is operated almost entirely on the duplex system. By this method the capacity of a wire is increased to about 500 words per minute.

Fig. 62 shows the connections necessary for working the Wheatstone duplex, and also the connections required to change the system from the automatic pole changer to the Morse pole changer. This change becomes necessary when it is desired to hold conversation or to balance the wire, and is made by means of the triple switch (*F*) contained within the transmitter. In the diagram the switch is arranged for the automatic system. One motion of the lever controlling the switch transfers it to the Morse. The connections may be readily traced by any one familiar with the duplex system. The circuit is as follows: From the earth at *E E* to the disc *D*, to lever *Z*, to right-hand button of switch to negative pole of battery, to left-hand button of switch and lever *C*, to disc *D* and central button of switch, thence to the receiver, where the circuit divides, one portion going through the galvanometer *G* to line, and the other through the galvanometer to rheostat and ground.

As the polarized relay is inaccessible, owing to its position in the receiver, the manner of obtaining a balance of the wire is different from that on the quadruplex. The distant station is requested to open or close his key. This presents a certain pole to line and gives the home galvanometer needle a certain deflection. The polarity of the home battery is now reversed, and if a different deflection is thereby caused, it is an evidence that the home station is out of balance, and the rheostat is adjusted until the galvanometer needle remains stationary under the changes of home polarity, when the balance is correct.

Fig. 63 shows the Wheatstone connections, as arranged for working the system on single wires. In this arrangement it will be seen that the circuit is from the earth to the galvanometer, thence to the middle button of the triple switch. Here the current has two

routes; one is to the pin 1 on the rocking beam *R*, thence to the crank lever *A*, thence to pin 2 on rocking beam, thence to disc *D*, to the battery, to the right-hand button on switch, thence to lever *Z* and disc *D*, and to the line. The other route is from the middle button of switch to an interposed resistance *R*, thence to the disc *D*, etc., as before. This interposed resistance is generally very high, so that when the route *via* the rocking beam is intact, only a very small portion of the current will go through the resistance, hence the full strength of current virtually goes to line. But when it happens, for instance, that the lever *M* is prevented, by reason of there being no hole in the prepared paper, from following pin

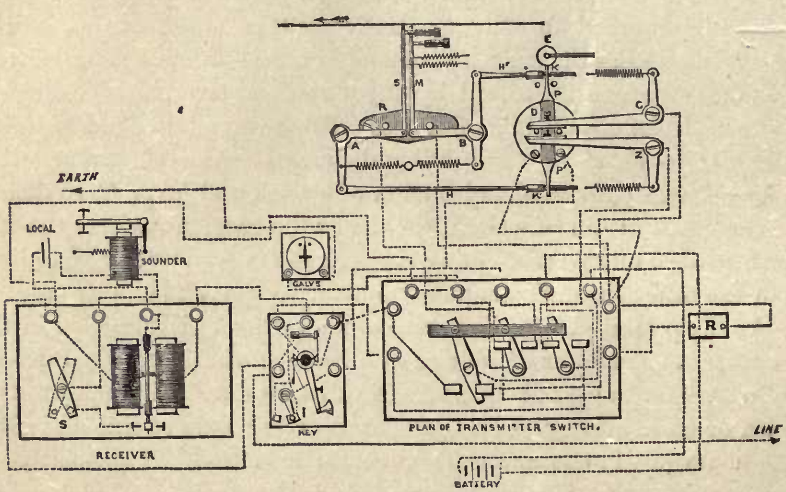


Fig. 63.

2 in the beam *R* in its upward motion, the circuit is broken at that point, and the current is compelled to go through the resistance *R*, and the strength of the current is thereby greatly diminished; but, as we have seen that when either of the levers *S* or *M* does not make its full motion, the polarity of the current is not changed, and as we also know that the tendency of the armature of the receiving relay is to stay where last placed, this diminished current will be

quite sufficient to keep the armature in its present position until the polarity of the current is again changed.

When the Wheatstone was first invented this resistance was not used, the wire being allowed to remain open while either of the levers *M* or *S* was detached from its respective pin 1 or 2, but it was found that greater speed could be attained by introducing the above resistance, as the wire is thus kept at the same potential until the next actual reversal of polarity.

The key shown in Fig. 63 is a double current or pole changing key. It is still used on the Wheatstone system in England, but has been displaced here by the ordinary pole changer, as shown in Fig. 62, it having been found that firmer contacts could be made by the latter method.

In Figs. 62 and 63 the transmitter switch is placed for automatic sending.

The punching instruments in the Wheatstone department at 195 Broadway, by means of which messages are prepared for automatic transmission, have recently been supplied with pneumatic pressure. Heretofore the operation of punching the paper has been quite arduous, as considerable force is required to perforate the paper with the precision which is essential. The old punching instrument, with its three discs, is still retained, but it is now placed within a tight-fitting iron frame. A small portion of the upper part of this frame is boxed in, and the air pressure is allowed to enter the box at one of the sides. Three cylindrical pistons protrude from the bottom of the box, and these pistons are placed directly over the discs of the ordinary punching instrument. The iron frame-work is also furnished with three keys, representing the three discs of the punching apparatus, and these keys control, by means of a stiff wire, three valves within the inclosed box. A slight depression of one of these keys thus opens its corresponding valve and allows the air to rush in, which forces the desired piston down with a quick, strong motion upon the disc beneath it, causing it to perforate the paper. The air pressure at present employed is six and one half pounds to the square inch.

Messages intended for transmission by the Wheatstone system are first handed to the perforators or punchers for preparation. The prepared paper is then placed on the transmitter by the clerk in charge of that instrument. Another clerk is in charge of the receiving instrument. As the messages are received on the receiving paper they are given to transcribing clerks, who translate the Morse characters into writing. These clerks are termed "writers."

Thus, by the automatic system, each message in the course of transmission and reception passes through the hands of four clerks, as against two by the Morse system.

The Wheatstone automatic telegraph is the standard automatic system of the British Postal Telegraph, and it is in extensive operation in that country. It is found very useful there, especially for press reports, on account of the fact that many similar special dispatches are sent to several different cities, and, as when the paper is once prepared, it may be used any number of times, much work is thus dispensed with. The automatic system is also found very serviceable in case of prostration of the wires, owing to storms or from any other cause, as in the meantime the business may be prepared for automatic transmission, and as soon as one or two wires are obtained, may be quickly disposed of.